Senior Thesis

Petrography of the Amphibolite-Granulite Facies Transition in Southern Norway

by
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Introduction

The amphibolite-granulite facies transition in the Rogaland/Vest Agder region of Southern Norway is associated with gneisses, migmatites, and anorthositic intrusions.

The onset of granulite facies metamorphism is usually marked by the appearance of hypersthene. Previous work in the area has established a hypersthene-in isograd only for leucocratic rocks, and no detailed study has been made of the reactions. Evaluation of the amphibolite-granulite facies transition requires petrological data from across the isograd; reactions at the transition will be different if the hypersthene-in isograd actually represents the onset of granulite facies metamorphism from different metamorphic episodes. Mapping the hypersthene-in isograd in all rocks is necessary to insure that analyses of transition reactions refer to the same metamorphic event.

This petrography of rocks collected in the area during the summer of 1987 will be followed by interpretation of whole-rock chemical analyses, electron microprobe analysis, and fluid inclusion studies. Rock samples were collected along valleys associated with major faults; rocks not subjected to retrograde metamorphism will be collected in the future and analyzed.

Southern Norway has undergone three metamorphic episodes. The first, about 1.5 billion years ago, reached upper amphibolite-granulite facies metamorphism. The second, about 1 billion years ago, reached high grade amphibolite facies. The last episode was retrograde amphibolite, about 0.9 billion years before the present.

Emplacement of the anothosites was synchronous with the metamorphic episode of 1.5 billion years ago, and osumilite and pigeonitè isograds within granulite facies rocks parallel the intrusion. The hypersthene-in isograd (taken as the onset of granulite facies metamorphism) however, does not parallel the intrusion. This suggests that granulite facies metamorphism may also be associated with a different heat source than the intrusion of the anorthosites.

Petrological studies of these rocks will enable evaluation of the factors responsible for the high-grade metamorphism represented by the granulites. Much of the continental crust is composed of granulites; the geophysical and geochemical data acquired from their study will provide information on crustal evolution.

Petrographic studies were made on a Leitz Ortholux polarizing microscope. Percentages of mineral contents in each thin section were estimated. The OSU electron microprobe was used to establish the identity of two minerals (ilmenite and augite).

Mineral Descriptions

•Quartz

Quartz is abundant in the leucocratic portions of these rocks. If often forms lenses or ribbons 1 or 2 cm long, particularly where granoblastic texture is well developed. These lenses may be associated with a rock texture that approaches granulitic. Crystals are anhedral.

Linearly arranged fluid inclusions are ubiquitous in this quartz, but particularly conspicuous or abundant occurrences are noted in the individual thin section descriptions. See more under "fluid inclusions".

Much of the quartz also contains linearly arranged solid inclusions. Solid inclusions in the quartz tend to be not as abundant, and larger, than the fluid inclusions. See more under "solid inclusions".

•Microcline

Microcline is anhedral, usually in crystals less than 2mm across. Microcline shows little or no sericitic alteration.

•Perthite

Perthite (or microperthite) is abundant in the leucocratic rock portions. Optic sign, and association with microcline in rock portions where plagioclase is scarce suggest that this is potas. feldspar with sodic feldspar intergrowth and not antiperthite (sodic feldspar with exsolved potassium feldspar). Sericitic alteration concentrated within plagioclase exsolution veins also supports the identification as perthite.

Perthite often forms large crystals 1cm in diameter. Perthite is anhedral, and occasionally contains large, ovoid plagioclase crystals.

•Plagioclase

Plagioclase is concentrated within the mafic rock portions. Plagioclase composition ranges from An_{28} to An_{38}. It is frequently on the oligoclase-andesine border, around An_{28} to An_{32}. There is no obvious relation between anorthite content and the mineral paragenesis.

Plagioclase identification was made on the basis of twinning, and anorthite content by Michel-Levy's method of albite-twinned crystal extinction. Some plagioclase shows no twinning, but was identified as such by large 2V, refractive index, etc.

Plagioclase shows much sericitic alteration. Granulite facies plagioclase shows the most intense alteration; much of the thin section is clouded by sericite.(thin section 2907889).

Plagioclase is in predominantly anhedral to subhedral crystals averaging less than 2mm, but much larger in rocks where a granoblastic texture is well developed. Some Carlsbad-Albite combination twinning is present, but most plagioclase is only albite-twinned.

Myrmekitic intergrowths of plagioclase and quartz are common, particularly in the leucocratic rock portions.

•Sericite

The clear mica to which much plagioclase alters is probably sericite. Where sericitic alteration is intense, small flakes of muscovite suggest that the sericite is fine muscovite, and not paragonite or illite.

Sericitic alteration of plagioclase is pervasive in many thin sections; such sections are extremely clouded in plane polarized light.

•Biotite

Biotite is present in major or minor proportion in all of these rocks. Crystals are anhedral to euhedral, and usually no longer than 2mm. Most biotite is in preferred orientation.

Pleochroism is usually typical for biotite, but in rocks with complex mineralogy where a granulitic texture is approached the biotite is very red.

Chlorite and ilmenite are frequently alteration or replacement products of biotite. Biotite is often intergrown with hornblende and clino-pyroxene, suggesting it is a replacement of those minerals.

•Hornblende

Hornblende forms anhedral to subhedral crystals up to 3mm across. Pleochroism is usually green to brown, but some thin sections show crystals with strong blue-green pleochroism.

Alteration or replacement of hornblende to biotite and ilmenite is very prevalent.

•Ilmenite

The opaque mineral is probably ilmenite, but there are reasons to suggest the ilmenite may be intergrown with magnetite.

In thin section this opaque mineral appears to be slightly translucent. Flakes have a very distinct violet tint, and darker color bands, fractures, and black rims around the crystals further suggest translucence. The violet color, however, is a reflected light phenomenon. Fragments and crystals are opaque.

Parallel light and dark banding within flakes suggests intergrowth with magnetite (Basu, 1989).
Thin sections with a high content of this opaque are perceptibly magnetic (2407878-C in particular). It is doubtful whether the magnetism of ilmenite alone would be noticeable. High titanium content of the mineral (as determined by use of the OSU electron microprobe) eliminates the possibility that the opaque is entirely magnetite.

Most crystals are anhedral but a small percentage are perfectly square. Ilmenite replaces biotite, hornblende, clinopyroxene, hypersthene, and chlorite. It is found intergrown with biotite in spindly fragments, and as small, particulate inclusions in hornblende and clinopyroxene. Some is intergrown with epidote, chlorite, and carbonate.

•Hypersthene

Hypersthene is associated with a variety of rock textures in these thin sections, and not limited to occurrence within those with a typical granulitic fabric.

Most hypersthene shows the characteristic pink-green pleochroism. Crystals are subhedral and usually highly fractured. Serpentine often fills the fractures and rims the exterior of hypersthene crystals.

Ilmenite and hornblende replace hypersthene in some rocks. In some thin sections, only minute fragments of hypersthene remain. Thin section 2907875-A contains serpentine in a form similar to that which occurs as an alteration product of hypersthene, though no hypersthene is present.

•Clinopyroxene - Augite?

A clinopyroxene of a composition probably in the augite range occurs in the mafic portions of some rocks, and is generally associated with hypersthene, hornblende, biotite, and ilmenite.

Identification of the clinopyroxene as <u>augite</u> was made on the basis of optical information (2V-60°(+), moderate birefringence) and a relatively high Fe^{+2} peak on the OSU electron microprobe. It is possible, however, that this clinopyroxene is a member of the diopside-hedenbergite series, such as salite or ferrosalite.

The clinopyroxene is in anhedral to subhedral crystals up to 3mm long. Replacement of clinopyroxene by hornblende, ilmenite, and biotite is common. In thin section 2907875-C clinopyroxene is intergrown with hypersthene.

•Chlorite

Most chlorite is intergrown with biotite. Some groups of chlorite crystals may be an alteration product of actinolite (thin section 2407871-A). Chlorite fills the fractures of some plagioclase. Thin section 2407881 contains about 20% chlorite in randomly oriented crystals. Chlorite is probably of primary origin in this rock, and not a mineral of alteration or replacement.

Chlorite shows typical anomalous blue and brown birefringence. Crystals are radiating, or long and spindly where altering from biotite.

•Apatite

Apatite is usually an accessory mineral most heavily concentrated in the mafic rock portions. Crystals are subhedral or euhedral and up to 0.05cm across.

•Epidote

Epidote is an accessory mineral. It sometimes fills fractures in plagioclase but is usually intergrown with ilmenite and carbonate or chlorite. In thin section 2407871-A epidote crystals are located at the border between chlorite and actinolite.

Epidote is recognized by yellow pleochroism, high birefringence, radiating habit, and high 2V(-).

•Carbonate

A highly birefringent, uniaxial(-) mineral that may be calcite or dolomite is an accessory in rocks that show much reaction or alteration (complex mineralogy, much sericitic alteration, chlorite within fractures, etc.). The carbonate is usually intergrown with ilmenite or epidote, and only appears as small flakes.

•Sphene

Sphene identification was made on the basis of extreme relief, brown color in plane polarized light, extreme birefringence and dispersion, and moderate 2V(+). Most sphene is intergrown with ilmenite or forms thin borders around ilmenite crystals. Only a very small portion of sphene crystals are euhedral, since most sphene is associated with growth within or around ilmenite. Sphene is usually an accessory mineral and is always associated with ilmenite.

•Serpentine

Serpentine is seen only as an alteration of hypersthene, in vein fillings and around hypersthene edges. The crystal habit is generally very fibrous, and optical confirmation of the identity of serpentine comes only from one or two well oriented fragments with a high 2V(-).

•Actinolite

Thin section 2407871-A shows several intergrowths of actinolite, chlorite, and epidote. Fibrous to bladed actinolite crystals are surrounded by a rim of chlorite, with some epidote intergrown at the margin.

Establishing the identity of the mineral as actinolite (and not sillimanite which it superficially resembles) was made on the basis of mineral paragenesis and optical data (high 2V(-), inclined extinction, moderate relief, and slight green pleochroism.)

•Garnet

Garnet is found in two thin sections in small amounts. Crystals are subhedral to anhedral and up to 5mm across. The garnet is highly fractured but contains few inclusions. Garnet appears to partially replace staurolite in thin section 2907890.

•Staurolite

Found only in thin section 2907890. Staurolite is highly altered to an unknown, finely disseminated, colorless mineral and appears very clouded in plane polarized light. It is anhedral in crystals up to 1cm long, with myrmekitic intergrowth of quartz throughout. Color is yellow-green, and because the staurolite is so highly altered optical confirmation of its identity is impossible.

•Muscovite

Muscovite is found only where sericitic alteration is extensive. It is only present as an accessory mineral. Crystals are subhedral and no more than 0.01cm long.

•Zircon

Zircon is found in small euhedral or subhedral crystals within biotite and chlorite. Some zircon forms anhedral and subhedral crystals up to 0.05cm in diameter, but these are rare.

•Spinel, Brookite

These minerals are of very minor occurrence. Spinel forms flakes 20 to 50 microns across, and was identified as such because of its high relief and dark red color. A very high relief, small 2V(+) mineral that forms subhedral to euhedral crystals in thin section 2907890 may be brookite.

•Fluid inclusions

Quartz and some plagioclase contain linearly arranged fluid inclusions. Many of the inclusions are two-phase, as indicated by the presence of small vapor bubbles within the inclusion. Inclusions are usually oblong, with the long axis of the inclusion parallel with the lineation of the inclusions. Length of the inclusions averages about 2 or 3 microns. Much of the quartz contains lines of inclusions that intersect the boundaries between surrounding crystals. Where lineation is very conspicuous there often solid inclusions interspersed. There may be a subtle correlation between direction of fluid inclusion lineation and the preferred orientation of the long axes of quartz crystals and quartz lenses within the rocks.

•Solid inclusions

Solid inclusions are most numerous in plagioclase but occasionally are found in quartz and biotite. A variety of minerals is present but the identity of any has not been established.

Very thin flakes and needles strongly delineate the cleavage planes of plagioclase. Though solid inclusions in quartz as a group tend to be linear, individual crystals are randomly oriented.

Many crystals in plagioclase and quartz are hexagonal and dark red or brown, suggesting hematite. Crystals are up to 20 microns across. Tabular, rectangular blue, green, and brown crystals may be spinel, and rodlike inclusions could be tourmaline or rutile. The biotite in thin section 2407878-B is pervasively rutilated.

Though solid inclusions are common throughout these rocks, particularly abundant occurrences are noted in the individual thin section descriptions.

Thin Section No.	quartz	microcline	perthite	plagioclase	hypersthene	cpx	biotite	hornblende	ilmenite	sericite	apatite	chlorite	epidote	carbonate	serpentine	muscovite	sphene	zircon	other
2407871-A	•	•	•	•			°		°	•		°	°	°				°	act°
2407871-B	•		•	•		•	°	•	•	•	°	°	°	°		°		°	
2407872	•	•	•	•		•	°	•	•	°	°	°						°	
2407873	•		•	•	°	•	•	•	•	•	•	°		°	°	°		°	
2407874	•		•	•			•		•	•	°	°						°	
2407875-A	•	•	•	•			•		•	•	°	°				°		°	
2407875-B	•	•	•	•	°		•		°	•	°				°	°		°	
2407876	•	•	•	•			°	•	•	•	°	°						°	
2407877	•		•	•			•	•	°	•	°							°	spin°
2497878-A	•	•	•	•		°	•	•	°	•	°	°						°	
2407878-B	°	•	•	•			•		•	•	°	°				°		°	
2407878-C	°			•	•	•	•	•		°	°	°			°			°	
2407879-A	•		•	•			°		°	•		°				°		°	
2407879-B	•	°	•	•	°		•	•	•	•	°	°			°	°		°	
2407880-A	•		•	•			•		•	•	°	°				°		°	
2407880-B	•		•	•			•	•	•	•	°	°						°	
2407881	•	°	•				•		•	•	°	•	°	°		°	°	°	

•Mineral $\geq$ 1 % thin section content

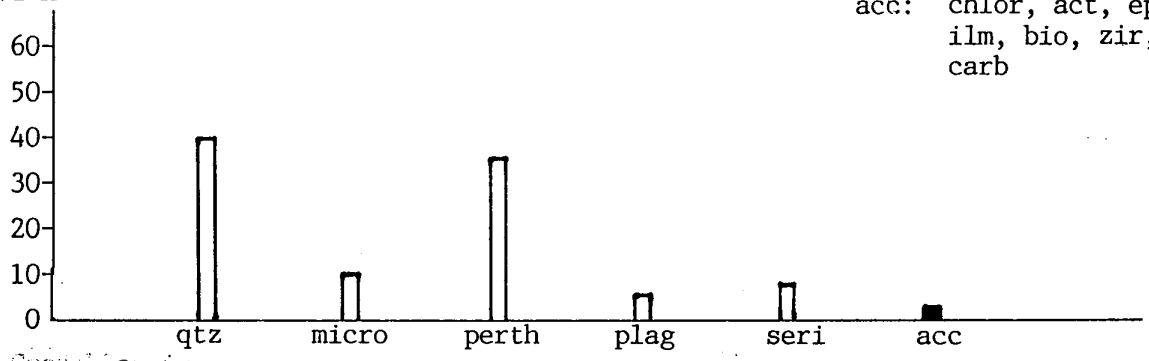
°Mineral < 1 % thin section content

cpx - clinopyroxene
act - actinolite
spin - spinel

Thin Section No.

2407871-A

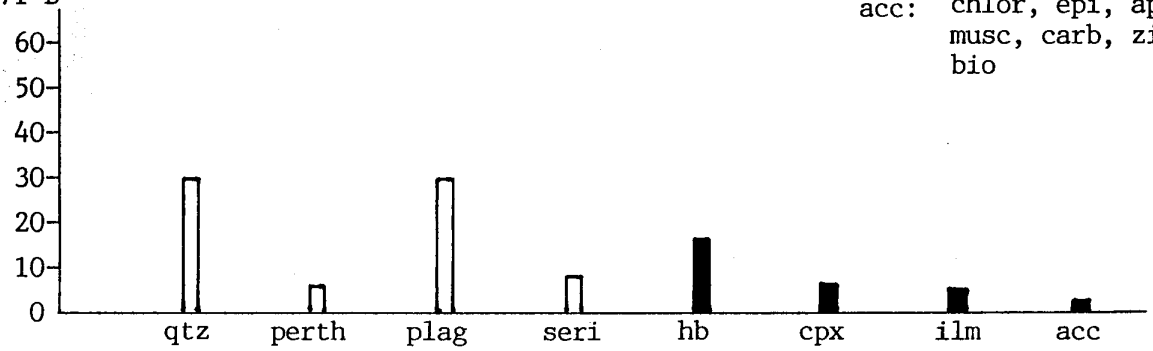
acc: chlor, act, epi, ilm, bio, zir, carb



Granoblastic. Some myrmekite. Abundant linear fluid inclusions in quartz. Actinolite fibrous and rimmed by chlorite; epidote at chlorite-actinolite border. Carbonate and chlorite fill plagioclase and ilmenite fractures.
•bio -> chlor; act -> chlor; plag -> ser.

2407871-B

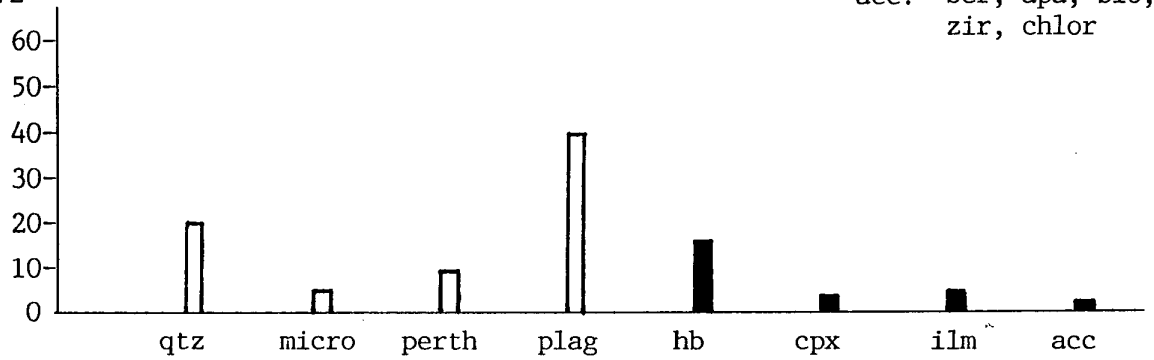
acc: chlor, epi, apa, musc, carb, zir, bio



Slight foliation. Some myrmekite. Abundant fluid inclusions in quartz. Chlorite vein fillings in plagioclase fractures.
•hb -> chlor, hb -> ilm, hb -> cpx?; plag -> ser.

2407872

acc: ser, apa, bio, zir, chlor

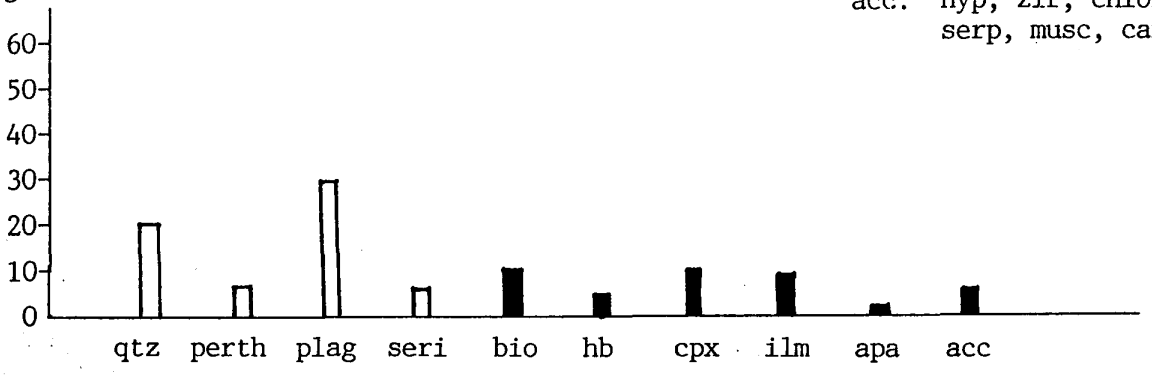


Very slight foliation. Some myrmekite.
•bio -> chlor, bio -> ilm; hb -> bio; plag -> ser.

Thin Section No.

2407873

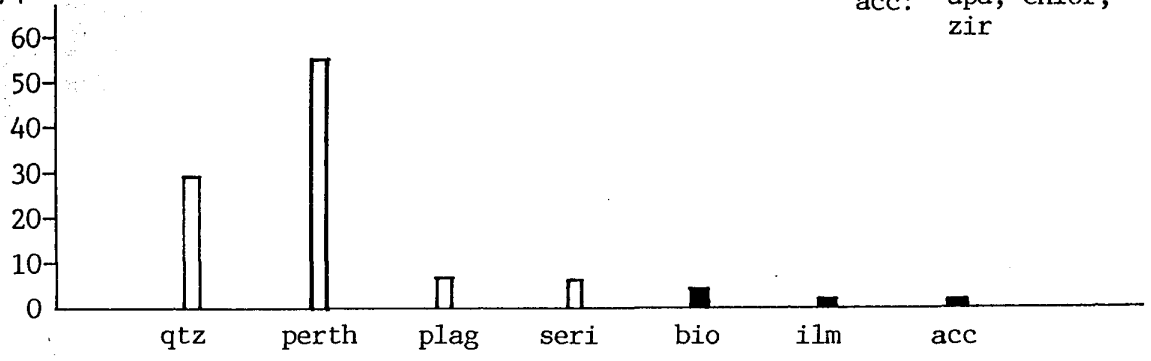
acc: hyp, zir, chlor, serp, musc, carb



Slight foliation. Some myrmekite. Many solid inclusions in plagioclase.
•hyp -> serp; hb -> bio, hb -> ilm, hb -> cpx?; bio -> cpx, bio -> chlor, bio -> ilm; cpx -> ilm; plag -> seri.

2407874

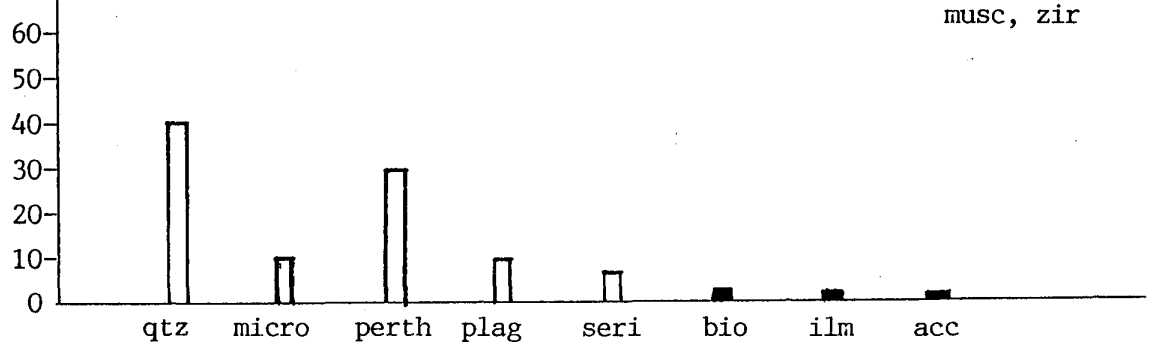
acc: apa, chlor, zir



Slight foliation. Some myrmekite. Much quartz in long, ribbon-like veins.
•bio -> chlor; plag -> seri.

2407875-A

acc: apa, chlor, musc, zir

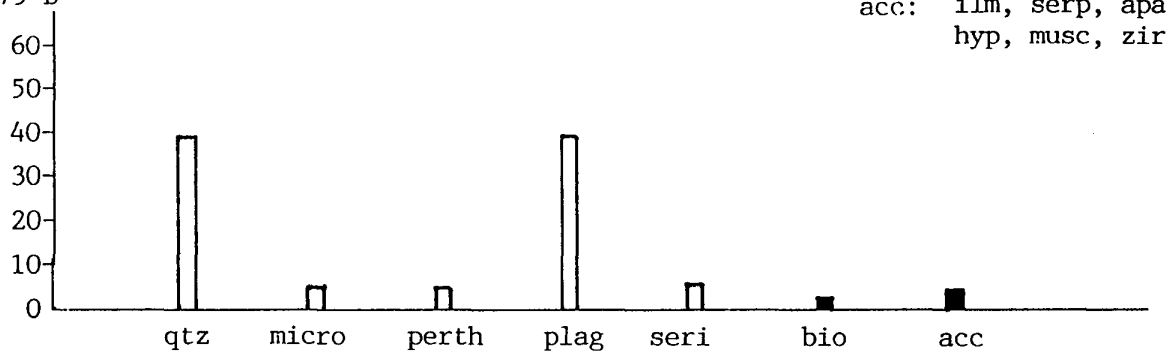


Very slight foliation. Some myrmekite. Many fluid inclusions in quartz.
•bio -> chlor, bio -> ilm; plag -> seri.

Thin Section No.

2407875-B

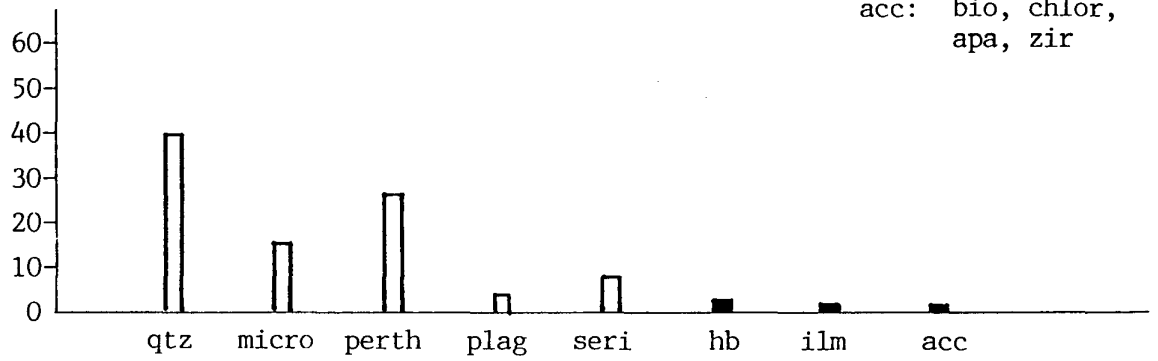
acc: ilm, serp, apa, hyp, musc, zir



Predominantly coarse granoblastic texture; very slight foliation. Some myrmekite.
•hyp -> serp; bio -> ilm; plag -> seri.

2407876

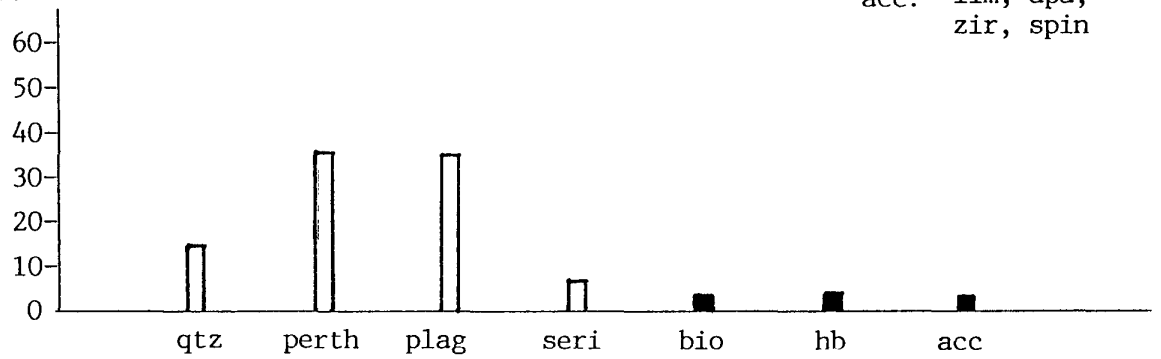
acc: bio, chlor, apa, zir



Predominantly granoblastic. Some myrmekite. Many linear fluid inclusions in quartz, and some solid inclusions in quartz and plagioclase. Chlorite fills fractures in some plagioclase.
•hb -> bio; bio -> chlor, bio -> ilm; plag -> seri.

2407877

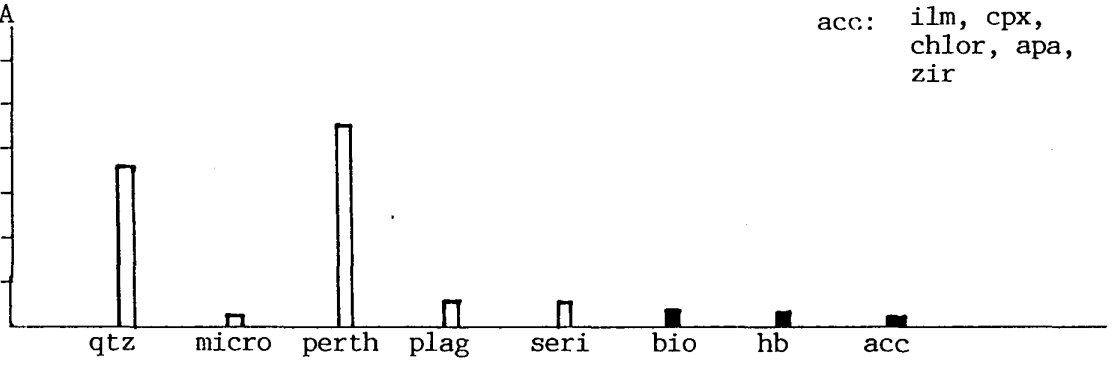
acc: ilm, apa, zir, spin



Predominantly granoblastic. Much plagioclase with blocky, "patchwork" extinction; some myrmekite. Many solid inclusions in plagioclase.
•hb -> ilm; bio -> ilm, bio -> hb?

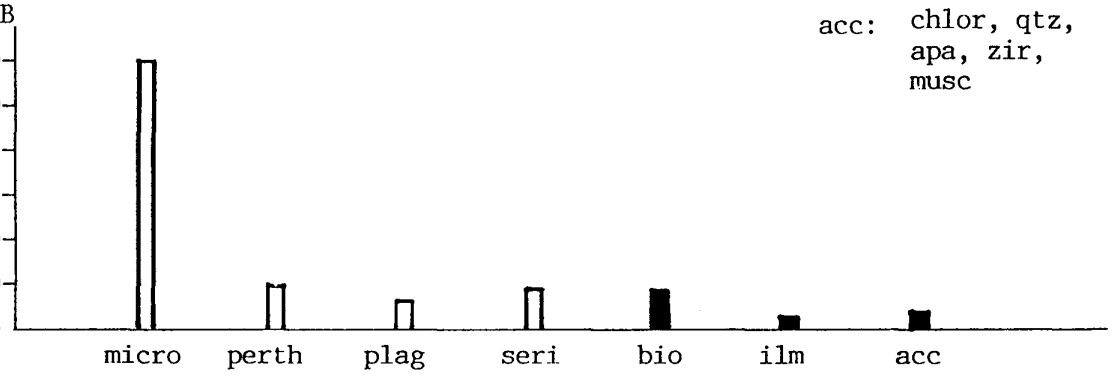
Thin Section No.

2407878-A



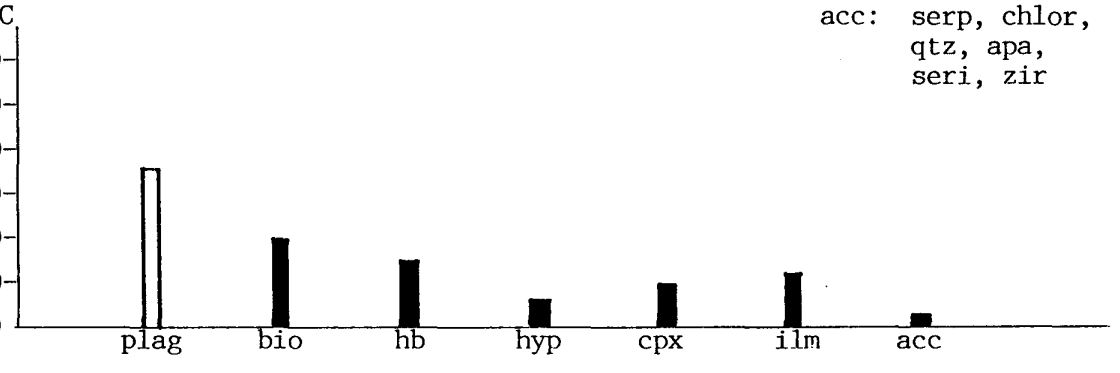
Foliated. Quartz in long, ribbon-like veins. Many solid inclusions in plagioclase and fluid inclusions in quartz. Some myrmekite.
•hb -> ilm; cpx -> hb; bio -> ilm; plag -> seri.

2407878-B



Granoblastic. Biotite highly rutilated.
•bio -> ilm.

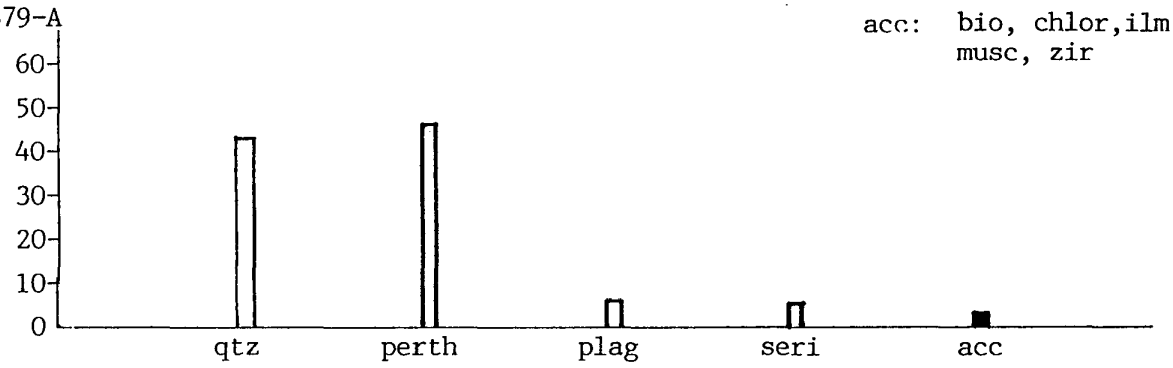
2407878-C



Well foliated. Thin section perceptibly magnetic.
•hyp -> serp, hyp -> ilm, hyp -> hb; cpx -> ilm; hb -> ilm; bio -> ilm.

Thin Section No.

2407879-A

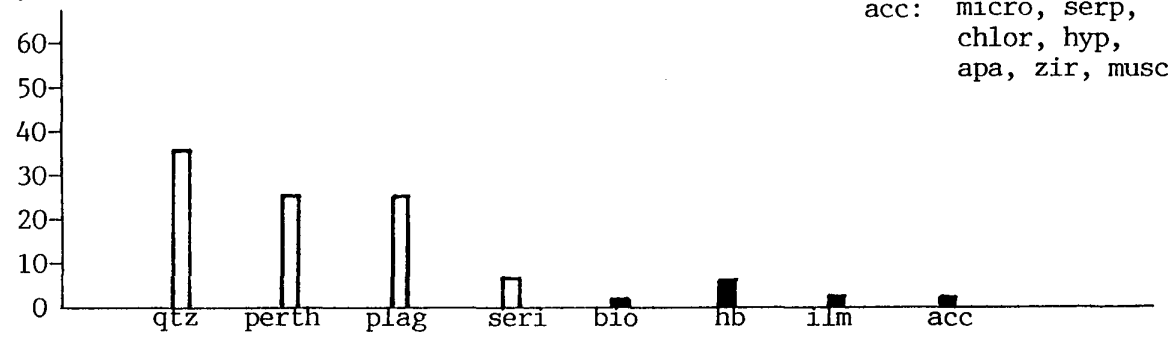


acc: bio, chlor, ilm, musc, zir

Very slight foliation. Much plagioclase has patchwork extinction. Quartz in long, ribbon-like veins. Some myrmekite. Abundant solid, linear inclusions in quartz.

•bio -> chlor; plag -> seri.

2407879-B

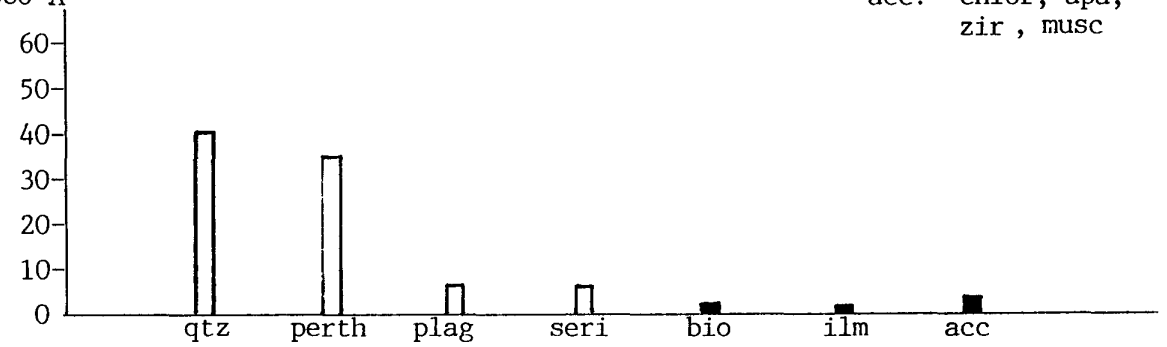


acc: micro, serp, chlor, hyp, apa, zir, musc

Foliated. Very irregular intergrowths of hypersthene, serpentine, ilmenite, and green biotite. Chlorite fills some fractures.

•hyp -> serp; hb -> ilm, hb -> bio; bio -> ilm, bio -> chlor; plag -> seri.

2407880-A



acc: chlor, apa, zir , musc

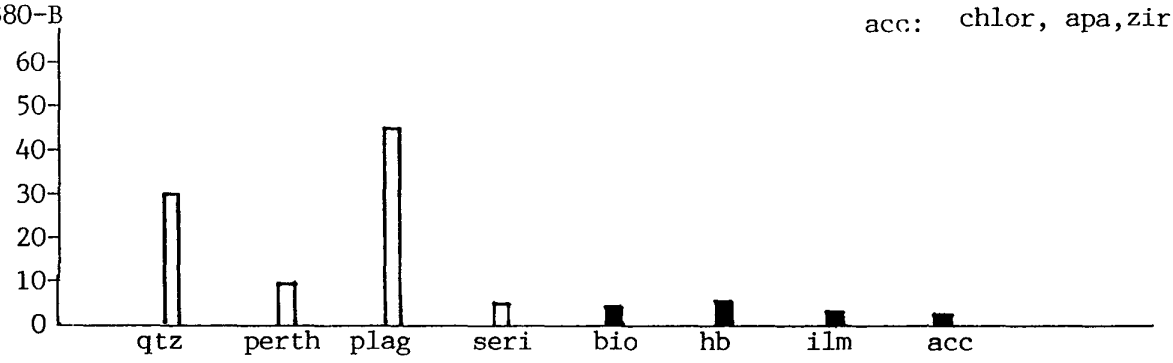
Very slight foliation. Quartz in long, ribbon-like veins; some in very large crystals (up to 1 cm). Some myrmekite.

•bio -> chlor; plag -> seri.

Thin Section No.

2407880-B

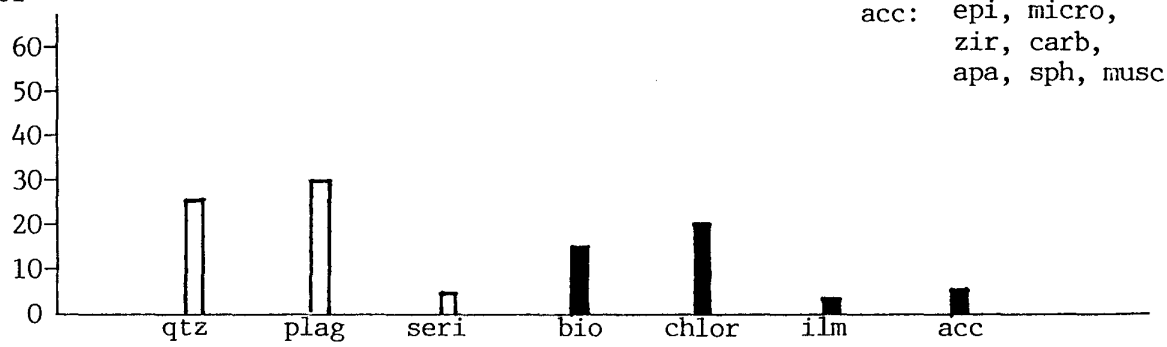
acc: chlor, apa,zir



Well foliated. Some myrmekite. Fluid inclusions in quartz.
•bio -> ilm, bio -> chlor; hb -> ilm, hb -> bio; plag -> seri.

2407881

acc: epi, micro, zir, carb, apa, sph, musc



Granoblastic; even chlorite randomly oriented. Many linear, fluid inclusions in quartz. Intergrowths of ilmenite-epidote, and chlorite-epidote.
•bio -> chlor, bio -> ilm; chlor -> ilm; plag -> seri.

acc:

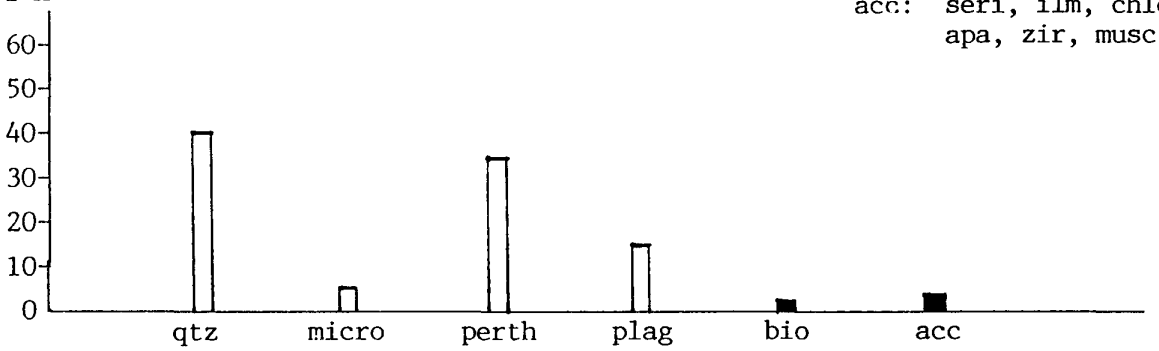
Thin Section No.	quartz	microcline	perthite	plagioclase	hypersthene	cpx	biotite	hornblende	ilmenite	sericite	apatite	chlorite	epidote	carbonate	serpentine	muscovite	sphene	zircon	other
2907871-A	•	•	•	•			•		°	°	°	°				°		°	
2907871-B	•			•			•		°	°	°	°	°	°			°	°	
2907871-C	°			•			•	•	•		•						°	°	
2907871-D	•		•	•			•	•	•	°	°	°	°				•	°	
2907872-A	•	•	•	•			•			•			°					°	
2907872-B	•		•	•			•	•	°	•	°							°	
2907873-A	•		•	•		•	•		•	•	•		°					°	
2907873-B	°			•			•	•	•	°	°							°	
2907873-C				•			•	•	°		°							°	
2907874-A	•			•			•		•	°	°	°	°					°	
2907874-B	•			•		•	°	•	•	°	•						°	°	
2907875-A	•		•	•			•		°	°	°	°		°	°			°	
2907875-B	•		•	•	•		•	•	•	°	•	°						°	garn°
2907875-C				•	•	•	°	•	•		•							°	
2907876-A	•	•	•	•			•		°	°	°	°				°		°	
2907876-B	•	•	•	•			•	•	•		•						°	°	
2907877-A	•	•	•	•			•		•	•	°	°				°		°	
2907877-B	•		•	•			•	•	•	°	°			°			°	°	
2907878-A	•	•	•	•			•	°	•	•	°	°					°	°	
2907878-B	•	•	•	•			•	•	•		°						°	°	
2907878-C		•	•	•			•	•	•	°	•					°	•	°	
2907879-A	•	•	•	•			•		°	•	°	°				°		°	
2907879-B	•		•	•		•	•	°	•	•	•	°	°					°	
2907880-A	•	•	•	•			°		°	•		°	°	°		°		°	
2907880-B	•		•				•	•	•	°	•	°	°					°	
2907880-C	•			•			•	•	•	•	•	°	°					°	
2907881	•			•		°	•	•	•	•	°		°					°	
2907882-A	•	•	•	•			•		°	°		°					°	°	
2907882-B$_{I}$	•			•			•	•	°	°				•				°	
2907882-B$_{II}$	•			•			•		°	•		•	°	°		°		°	
2907883-A	•	•	•	•	°		•		°	•	°	•				°		°	
2907883-B	•	•	•	•			•		•	•	°	°	°				°	°	
2907884-A	•	•	•	•			•		°	•	°	°						°	
2907884-B	•		•	•		•	•	°	•	°	•			°			°	°	
2907884-C	•		•	•		•	•	°	•	•	°			°			°	°	
2907885-A	•		•	•			°		°	°			°			°	°		
2907885-B	•		•	•		°	•	•	•	°	°	°					°	°	
2907885-C	•		•	•		°	•	•	•	°	°	°	°				°	°	
2907886-A	•		•	•			•		•	•	°	°		°		°		°	
2907886-B	•		•	•			•	•	•	°	°		°				°	°	
2907887	•		•	•		•			•	°	•	°	°					°	
2907888-A	•		•	•			•	•	•	•	°	°	°				°	°	
2907888-B	•		•	•		•	•	•	•	°	•		°					°	
2907889	•		•		•		•		°	•	°	°			•			°	garn•
2907890	•		•				°		°	•		°	°	°		°		°	staur•

•Mineral $\geq$ 1 % thin section content
°Mineral $<$ 1 % thin section content

garn - garnet
staur - staurolite
cpx - clinopyroxene

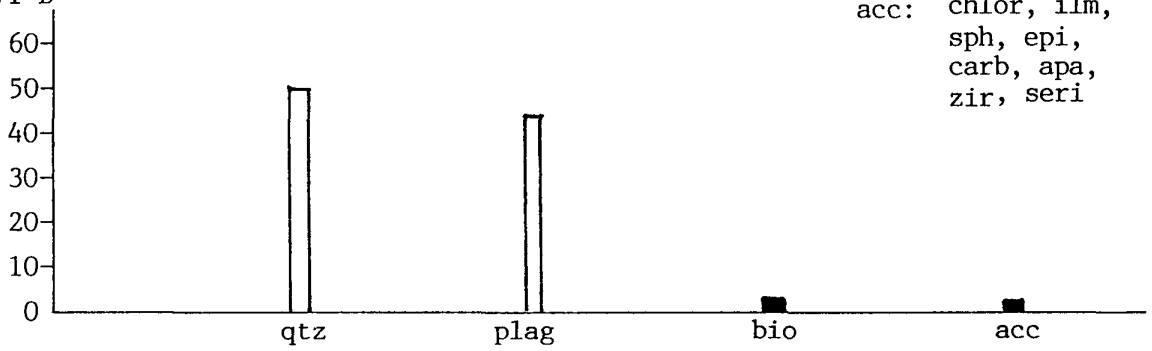
Thin Section No.

2907871-A



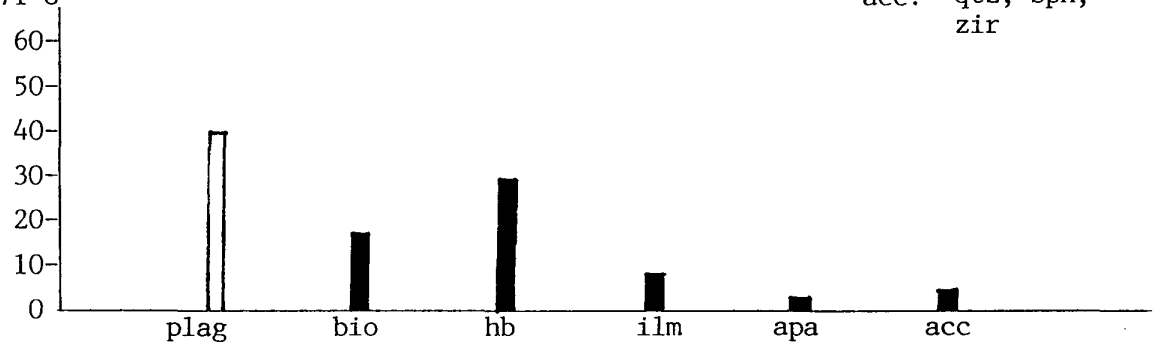
Granoblastic, very coarsely grained. Most crystals feldspar and quartz average 2 or 3 mm across. Some myrmekite.
•hb -> bio; bio -> ilm, bio -> chlor; plag -> seri.

2907871-B



Predominantly granoblastic, with only slight orientation of biotite. Sphene rims ilmenite. Intergrowths of ilmenite-carbonate-epidote-chlorite. Chlorite fills fractures, does not appear as replacement of biotite. Linear solid inclusions in quartz, some in plagioclase.
•bio -> ilm; plag -> seri.

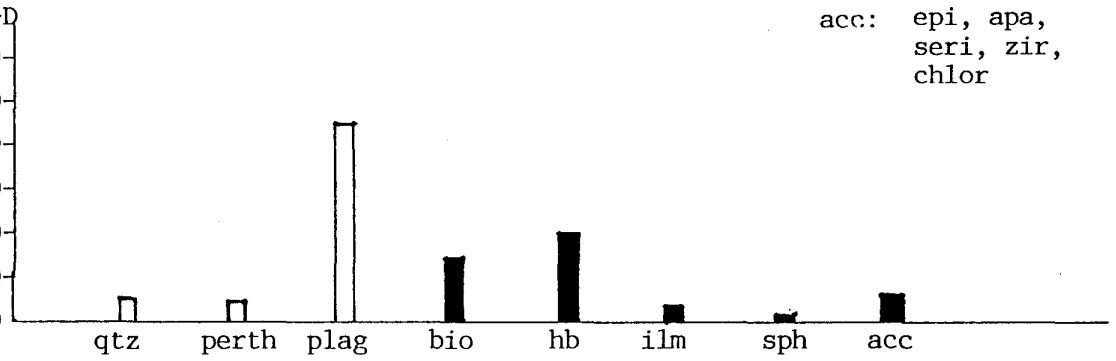
2907871-C



Well foliated. Sphene rims ilmenite. Hornblende-biotite intergrowths.
•hb -> ilm; bio -> ilm.

Thin Section No.

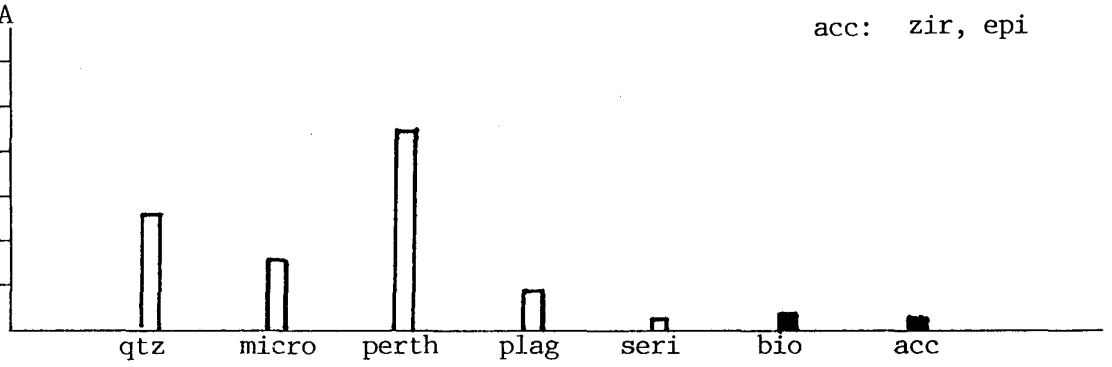
2907871-D



acc: epi, apa, seri, zir, chlor

Well foliated. Quartz in long, ribbon-like veins. Sphene rims ilmenite.
•hb -> bio, hb -> ilm; ilm -> sph: plag -> seri.

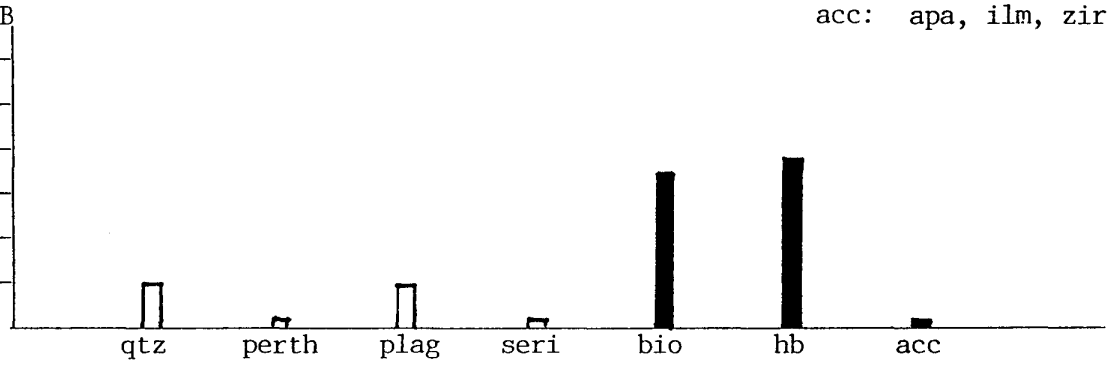
2907872-A



acc: zir, epi

Mostly granoblastic. Crystals coarse, up to 5 mm across. Much plagioclase shows highly blocky "patchwork" extinction. Quartz extinction highly undulatory. Much myrmekite. Biotite very red.
•bio -> ilm, bio -> chlor; plag -> seri.

2907872-B



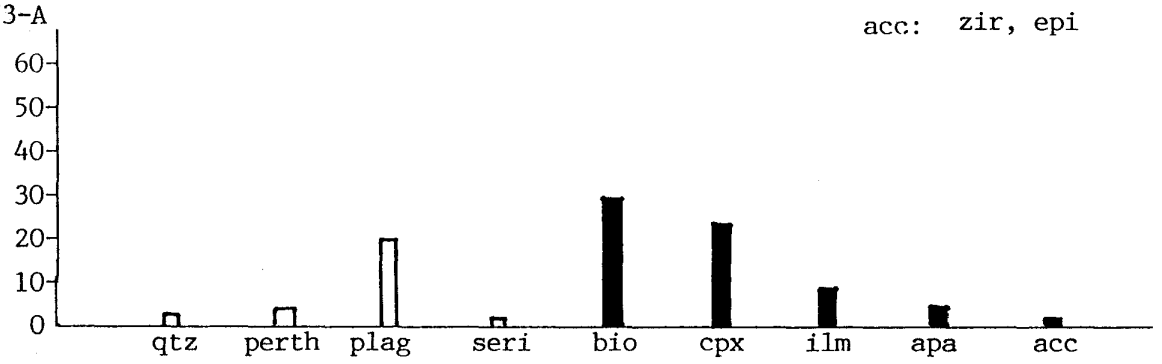
acc: apa, ilm, zir

Gneissic. Plagioclase crystals bent. Much hornblende shows strong blue-green pleochroism. Much hornblende-biotite intergrowth.
•hb -> ilm; plag -> seri.

Thin Section No.

2907873-A

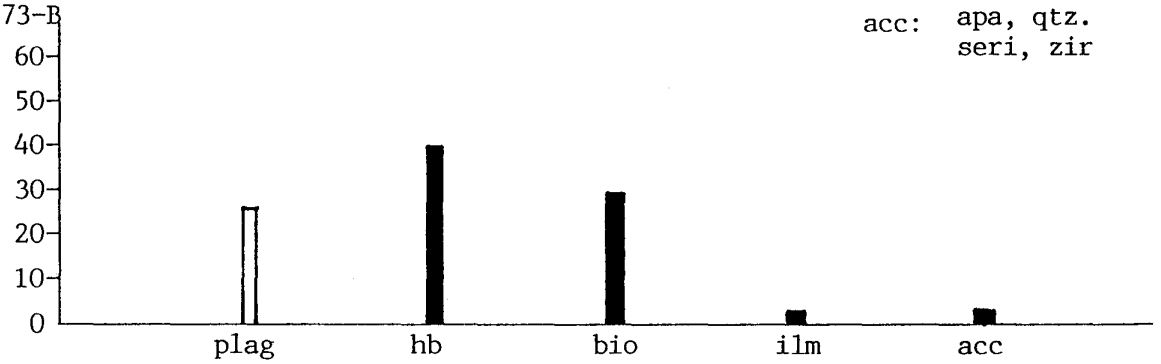
acc: zir, epi



Very slight foliation.
•cpx -> bio, cpx -> ilm; bio -> ilm, bio -> chlor; plag -> seri.

2907873-B

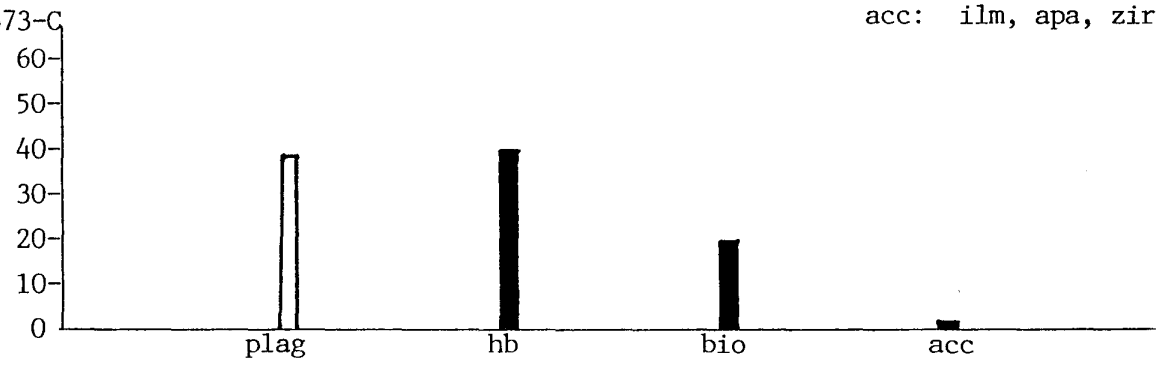
acc: apa, qtz. seri, zir



Very slight foliation - even mafic minerals show little preferred orientation. Biotite very red. Hornblende-biotite intergrowths.
•hb -> ilm, hb -> bio; plag -> seri.

2907873-C

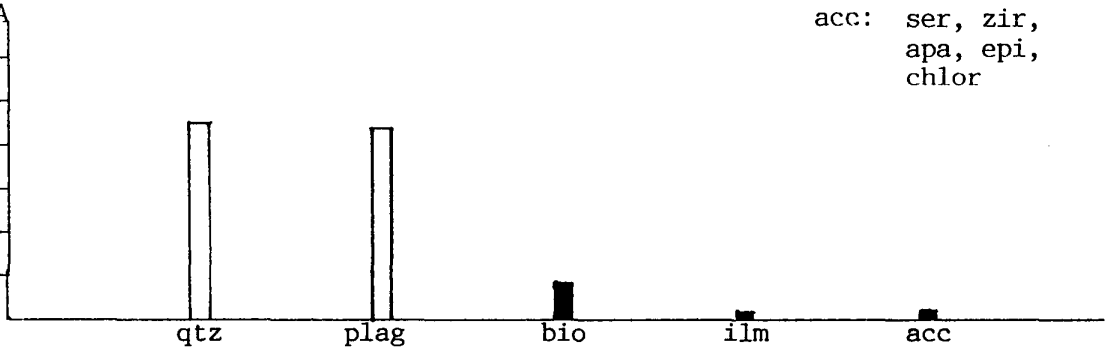
acc: ilm, apa, zir



Not well foliated, even among mafic minerals. Biotite very red.
•hb -> ilm, hb -> bio.

Thin Section No.

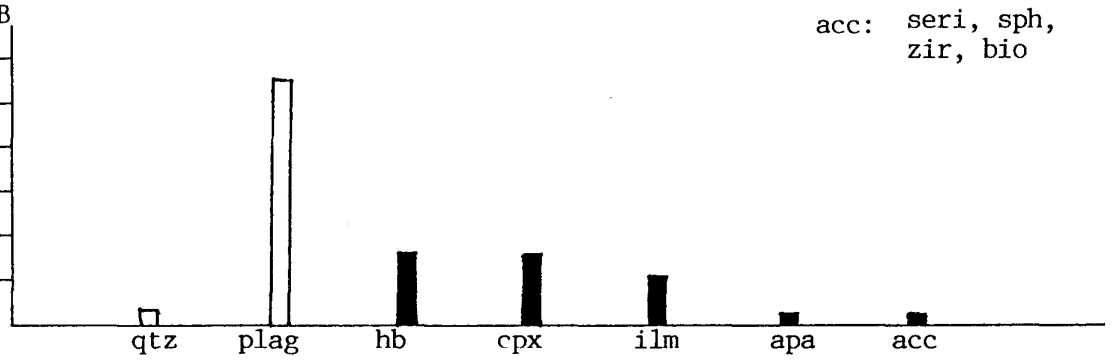
2907874-A



acc: ser, zir, apa, epi, chlor

Slightly foliated.
•bio -> chlor, bio -> ilm; plag -> seri.

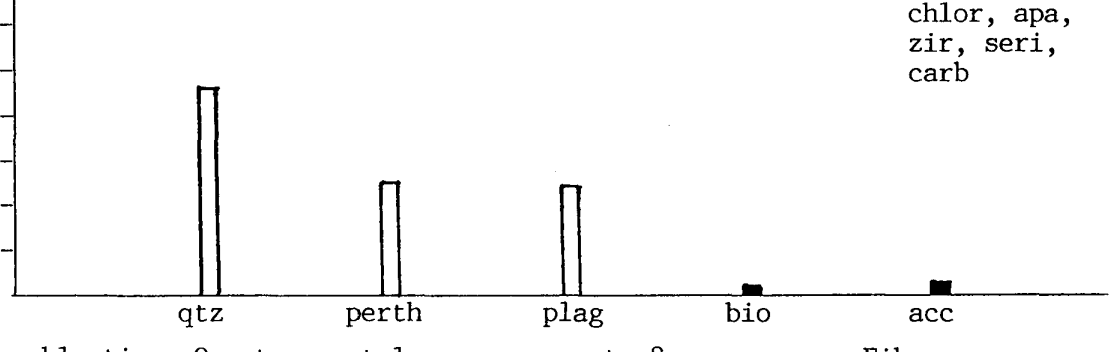
2907874-B



acc: seri, sph, zir, bio

Well foliated. Ilmenite-cpx-hornblende intergrowths.
•cpx -> ilm; hb -> ilm.

2907875-A

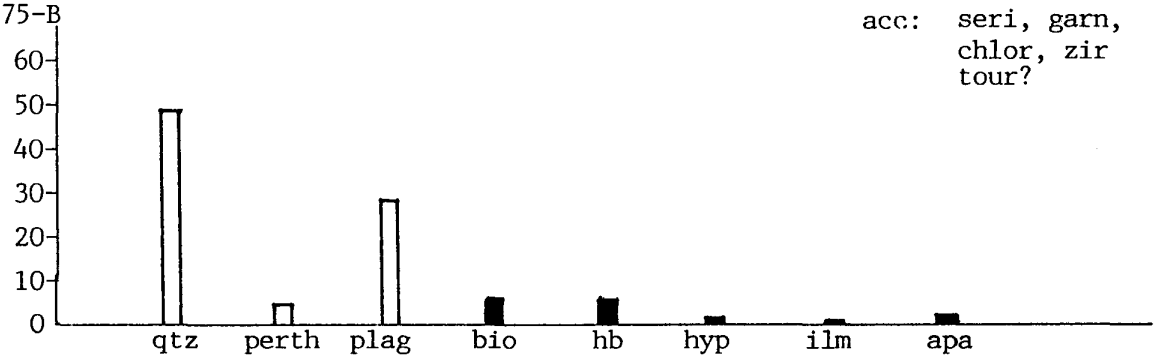


acc: serp, ilm, chlor, apa, zir, seri, carb

Granoblastic. Quartz crystals coarse, up to 8 mm across. Fibrous green mineral which may be serpentine probably replacement of hypersthene, though no hypersthene now evident.
•bio -> chlor, plag -> seri.

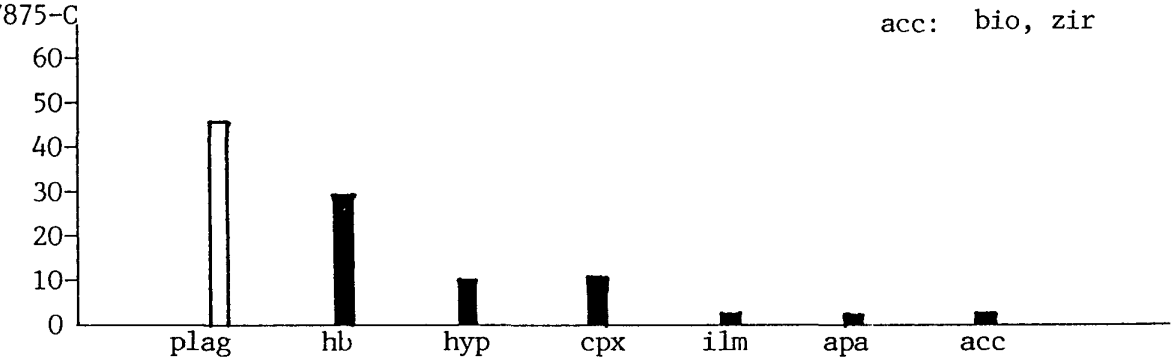
Thin Section No.

2907875-B



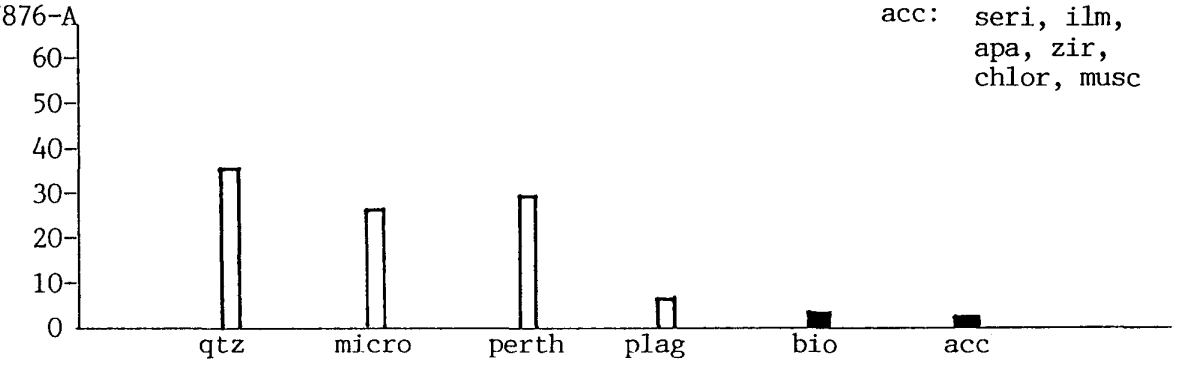
Well foliated. Carlsbad and albite twinning in plagioclase well developed. Hypersthene abundant in mafic layer. Quartz in long ribbons with abundant linear fluid inclusions. Quartz poikilitically encloses plagioclase. Biotite and ilmenite surrounded by garnet. Hypersthene extensively altered to yellow-brown unknown mineral, uniaxial(-); tourmaline? Biotite very red.
•bio -> ilm, bio -> garn?, bio -> chlor; plag -> seri: hyp -> bio?

2907875-C



Very well foliated. Hypersthene coarse, up to 8mm across. Hypersthene not altered in fractures to serpentine. Hypersthene-hornblende-ilmenite intergrowths, also hypersthene-cpx intergrowths.
•hyp -> ilm; cpx -> hb, cpx -> ilm; hb -> bio.

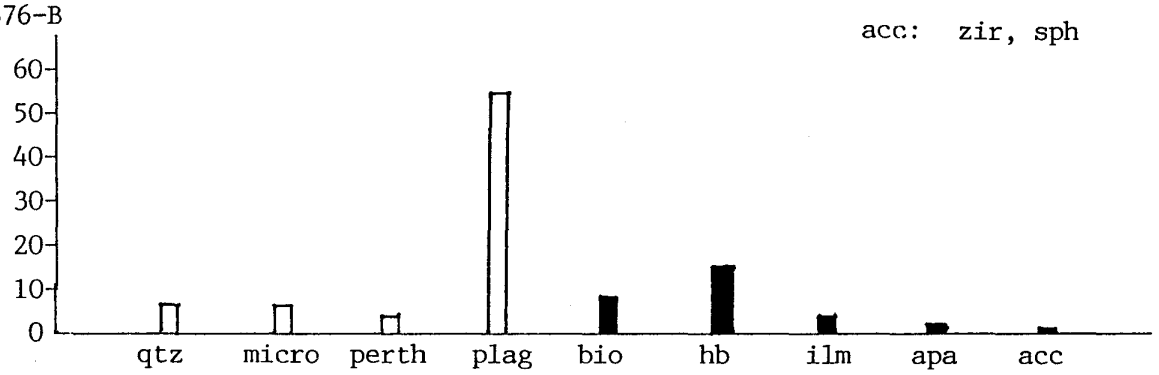
2907876-A



Predominantly granoblastic; very slight orientation of biotite. Very coarse; quartz and plagioclase-perthite crystals up to 8mm across. Some myrmekite.
•bio -> chlor, plag -> seri.

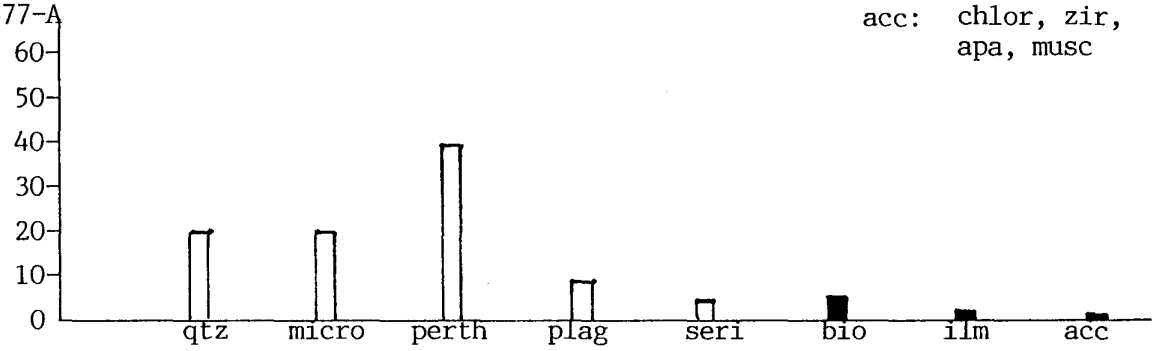
Thin Section No.

2907876-B



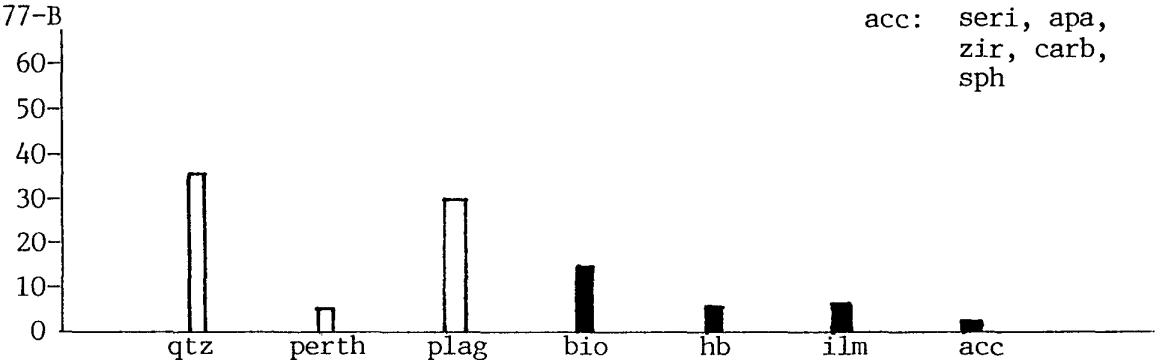
Granoblastic. Some myrmekite. Sphene-biotite intergrowth. Ilmenite rimmed by sphene.
•hb -> ilm, hb -> bio; bio -> ilm.

2907877-A



Granoblastic; crystals very coarse. Some myrmekite. Abundant linear fluid inclusions in quartz. Muscovite is localized where sericitic alteration is most extensive.
•bio -> ilm, bio -> chlor, plag -> seri.

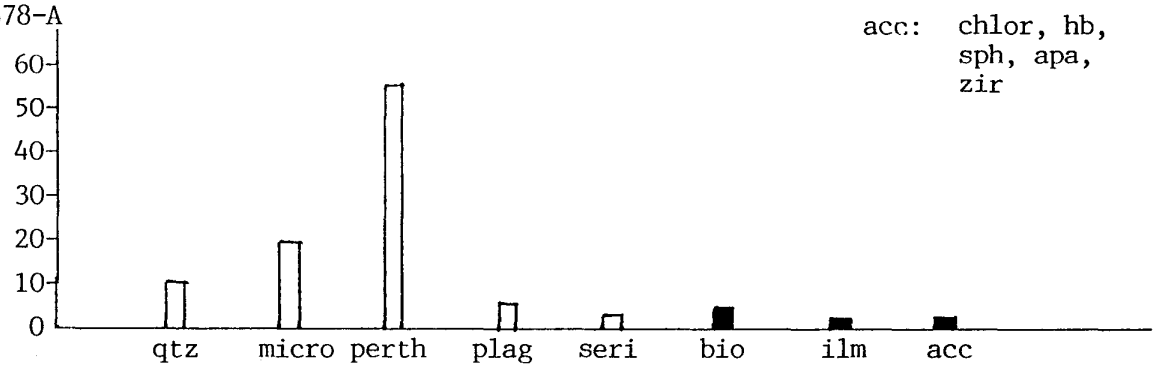
2907877-B



Well foliated. Sphene rims ilmenite. Some hornblende with blue-green pleochroism.
•hb -> bio, hb -> ilm; bio -> ilm; plag -> seri.

Thin Section No.

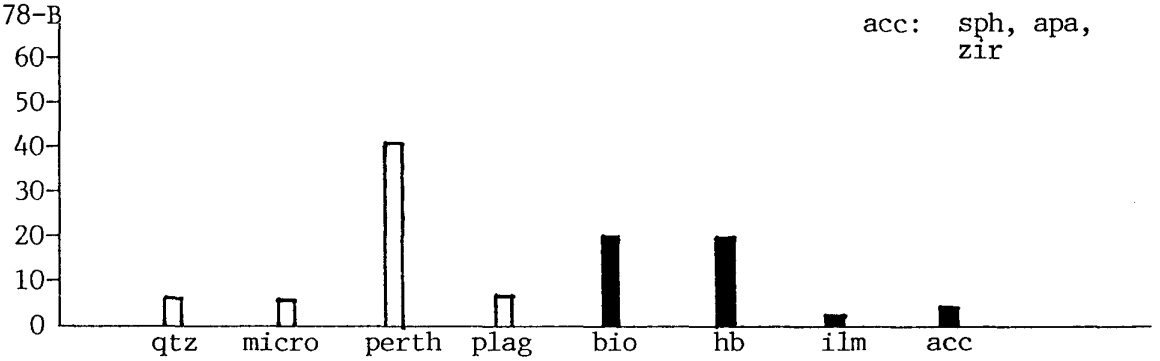
2907878-A



acc: chlor, hb, sph, apa, zir

Granoblastic. Quartz and microcline crystals average 2 or 3 mm in diameter. Some myrmekite.
•hb -> ilm, hb -> chlor?; bio -> chlor, bio -> ilm; ilm -> sph, plag ->seri.

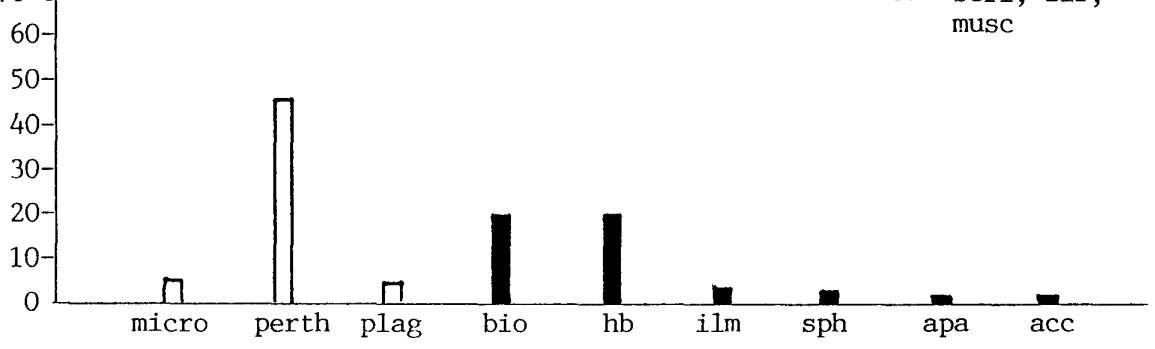
2907878-B



acc: sph, apa, zir

Slightly foliated. Thin section cut thin so difficult to estimate leucocratic mineral content. Some myrmekite. Ilmenite rimmed by sphene.
•hb -> bio; ilm -> sph.

2907878-C

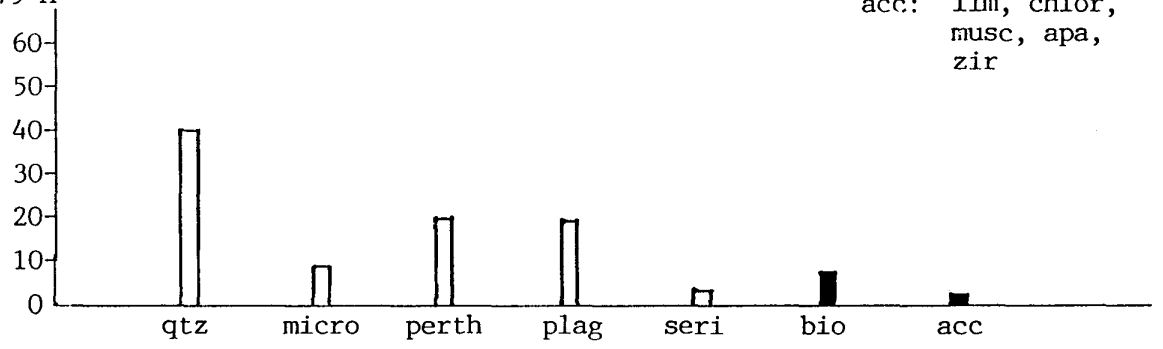


acc: seri, zir, musc

Slight foliation. Very coarse, perthite crystals up to 1 cm across. Much myrmekite. Ilmenite rimmed by sphene. Hornblende-ilmenite-sphene intergrowth. Some sphene up to 2 mm long.
•hb -> bio; bio -> ilm; ilm -> sph?; plag -> seri.

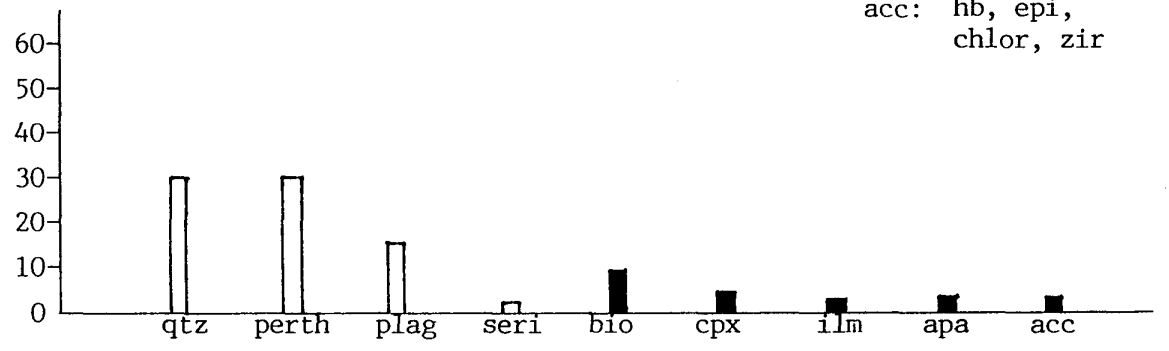
Thin Section No.

2907879-A



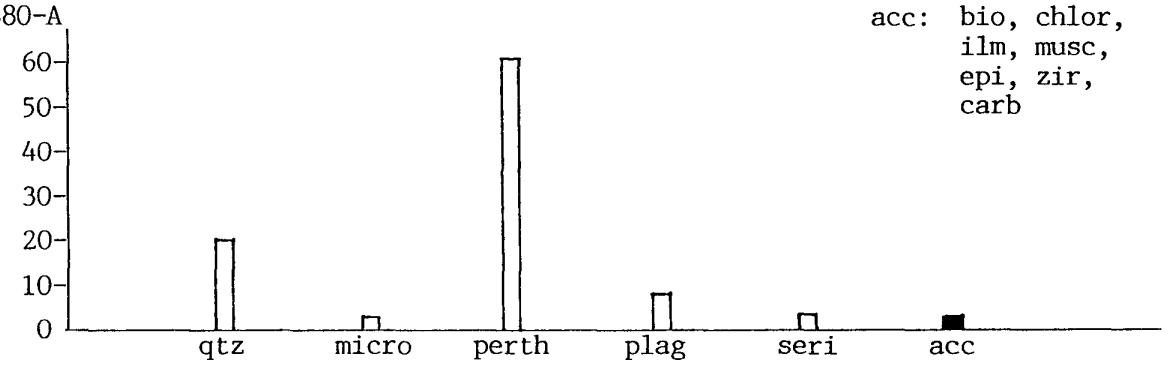
Granoblastic.
•bio -> chlor; plag -> seri.

2907879-B



Gneissic texture. Epidote fills fractures in plagioclase. Epidote-ilmenite intergrowth.
•cpx -> bio; bio -> ilm, bio -> chlor; cpx -> ilm; hb -> ilm; plag -> seri.

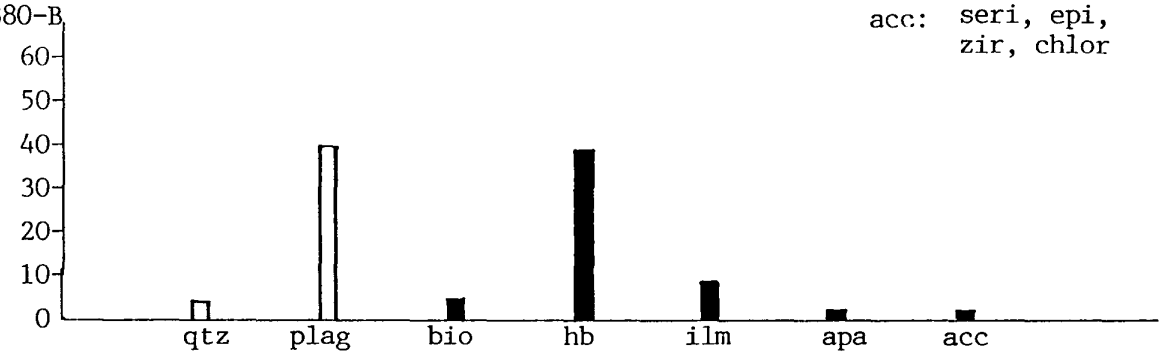
2907880-A



"Augen gneiss" texture, except plagiocalse forms "eyes". Quartz in long, ribbon-like veins. Linear fluid and solid inclusions in quartz. Much myrmekite along quartz-plagioclase boundaries. Abundant solid inclusions in plagioclase. Epidote-muscovite intergrowth, and bio-carb-chlor inter.
•bio -> chlor; chlor -> ilm; plag -> seri. May be migmatitic?

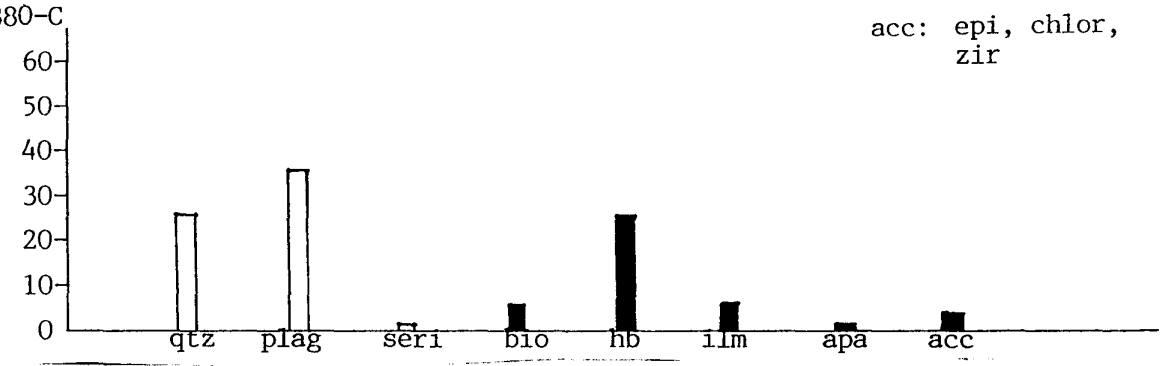
Thin Section No.

2907880-B



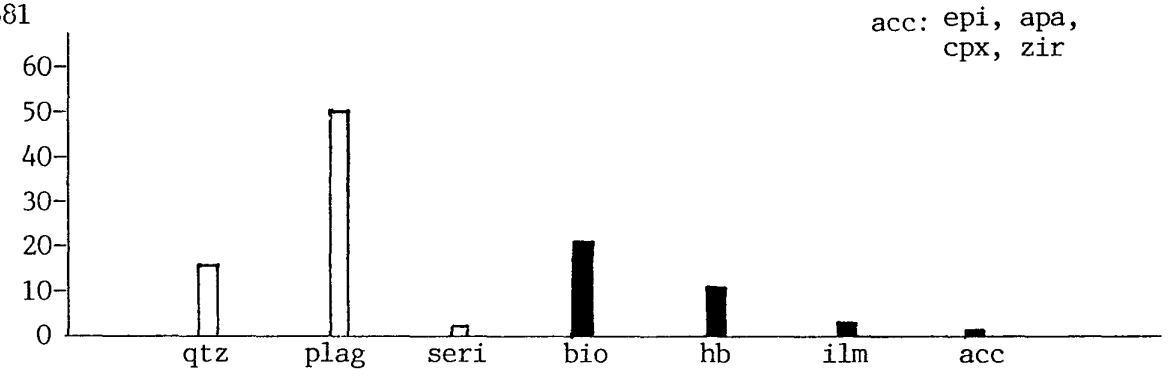
Well foliated; mafic portions roughly equigranular.
•hb -> ilm; bio -> ilm; plag -> seri.

2907880-C



Well foliated. Many linear fluid inclusions in quartz. Epidote-ilmenite intergrowth.
•hb -> ilm, hb -> bio; bio -> ilm; plag -> seri.

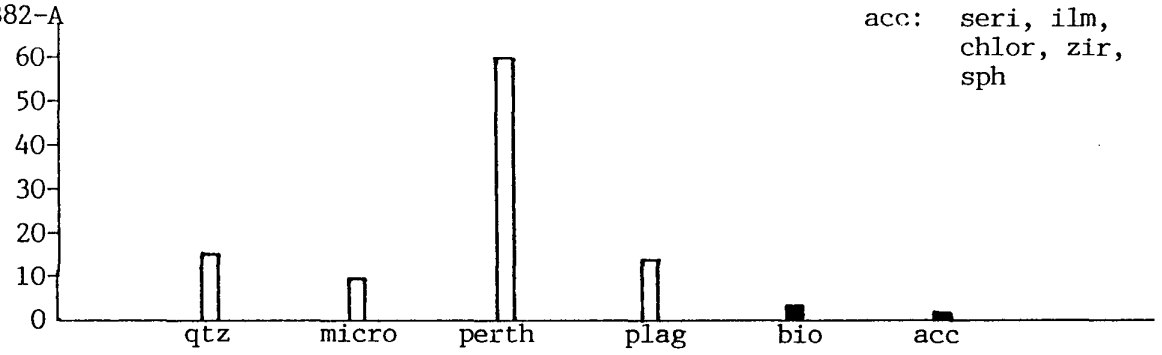
2907881



Slight foliation. Epidote-ilmenite-biotite intergrowth.
•hb -> bio, hb -> ilm; cpx -> ilm; bio -> ilm; plag -> seri.

Thin Section No.

2907882-A

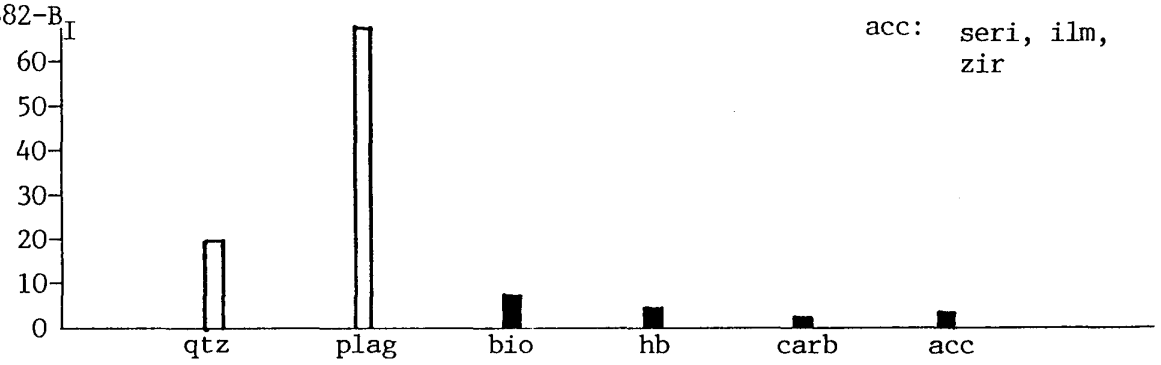


acc: seri, ilm, chlor, zir, sph

Granoblastic; very coarse. Some myrmekite. Large feldspar or perthite inclusions in plagioclase. Solid inclusions in plagioclase. Sphene rims ilmenite.

•bio -> chlor; plag -> seri.

2907882-B$_{I}$

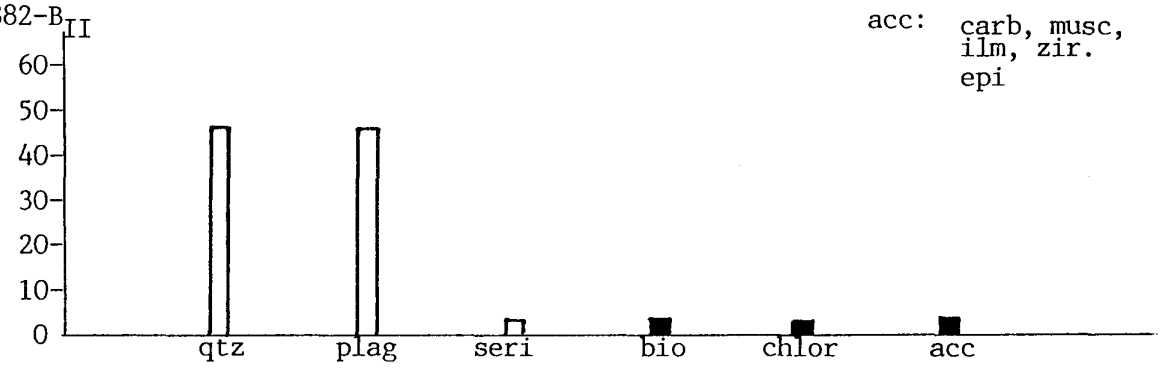


acc: seri, ilm, zir

Granoblastic. Quartz very coarse, up to 1 cm in diameter. Some quartz in long, ribbon'like veins edged by smaller, equigranular quartz and feldspar crystals. Chlorite-carbonate intergrowth.

•bio -> chlor; plag -> seri.

2907882-B$_{II}$



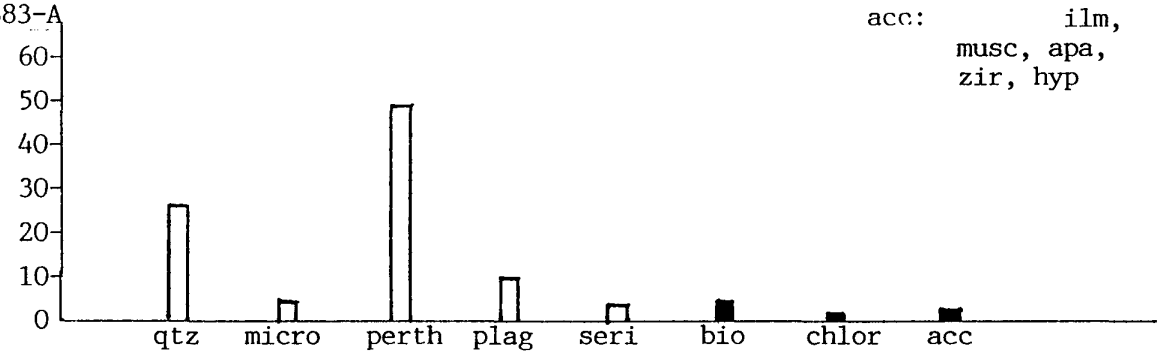
acc: carb, musc, ilm, zir. epi

Gneissic texture. Many long lens of quartz, up to 2 cm in length. Abundant linear fluid inclusions in quartz. Half of chlorite is intergrown with biotite. Biotite-chlorite-carbonate intergrowth. Muscovite-carbonate intergrowth.

•bio -> chlor; plag -> seri.

Thin Section No.

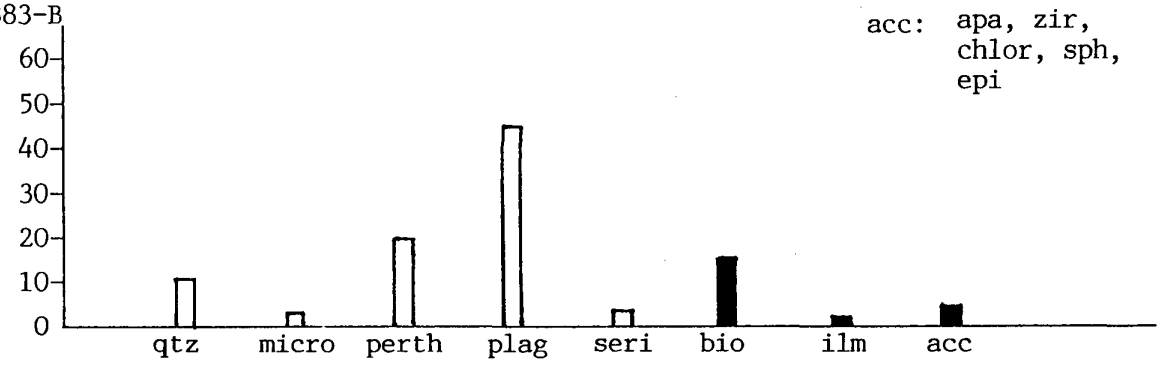
2907883-A



acc: ilm, musc, apa, zir, hyp

Foliated. Plagioclase with patchy extinction. Great number of solid inclusions in plagioclase; fluid and solid linear inclusions in quartz. Biotite in long, spindly crystals kinked and deformed. Biotite green. Ilmenite in long, skeletal crystals within biotite. Mafic minerals show much reaction, extreme lineation. Some myrmekite. Hb-hyp-ilm intergrowth.
•hyp -> hb; hb -> ilm; bio -> ilm, bio -> chlor; plag -> ser.

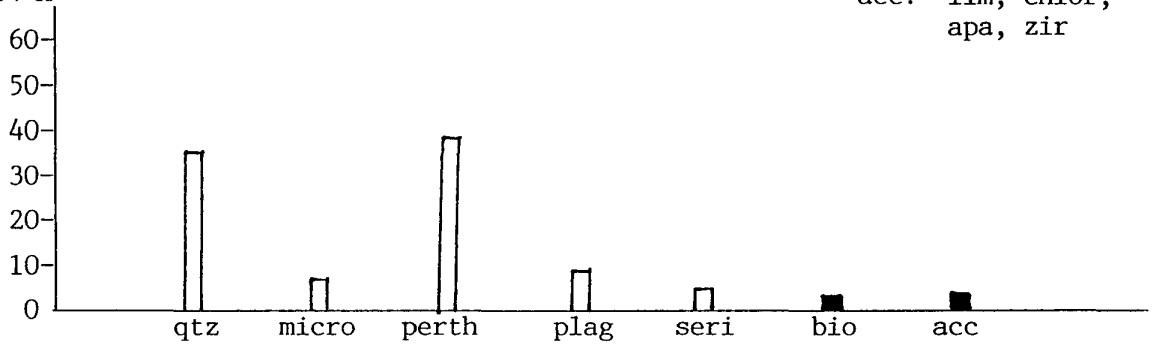
2907883-B



acc: apa, zir, chlor, sph, epi

Foliated. Epidote fills fractures in ilmenite. Much ilmenite skeletal.
•bio -> ilm, bio -> chlor; plag -> seri.

2907884-A

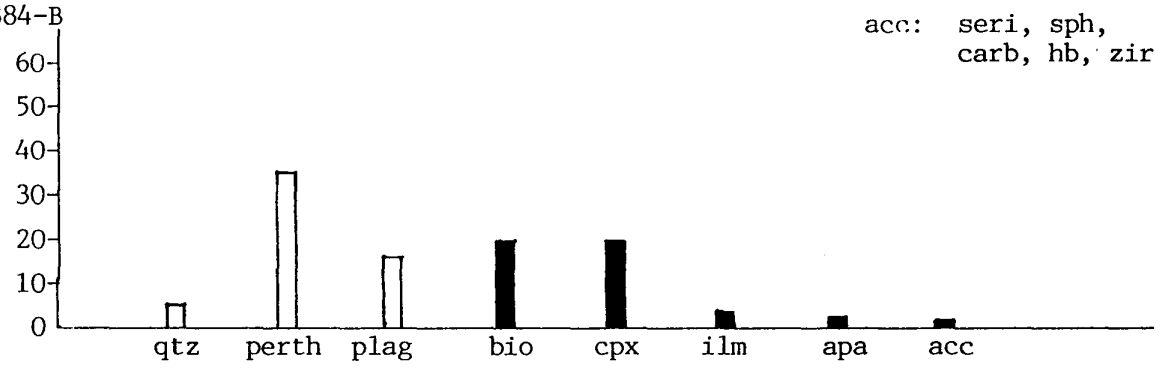


acc: ilm, chlor, apa, zir

Very slight foliation.Quartz in long, ribbon-like veins. Quartz contains linear solid and fluid inclusions. Solid inclusions in plagioclase. Patchy extinction of plagioclase. Much myrmekite.
•bio -> ilm, bio -> chlor; chlor -> ilm; plag≥seri.

Thin Section No.

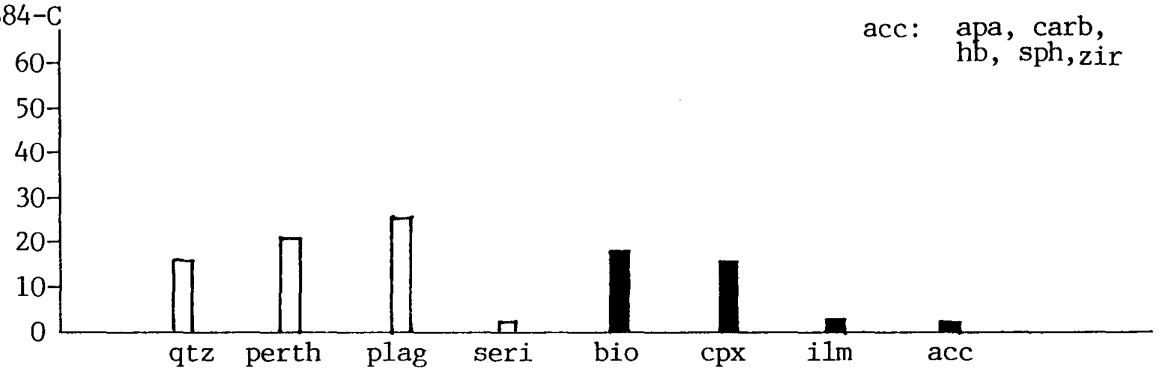
2907884-B



acc: seri, sph, carb, hb, zir

Well foliated. Much biotite-ilmenite intergrowth. Sphene borders ilmenite.
•cpx -> ilm, cpx -> hb; ilm -> sph: plag -> seri.

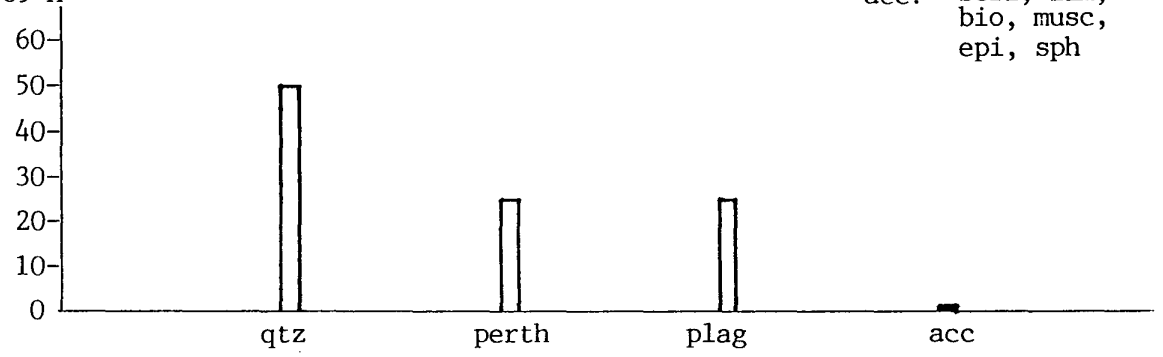
2907884-C



acc: apa, carb, hb, sph, zir

Gneissic texture. Some myrmekite. Fluid and solid inclusions in quartz. Hornblende within clinopyroxene. Sphene surrounds most ilmenite. Much clinopyroxene-ilmenite intergrowth.
•cpx -> bio, cpx -> ilm, cpx -> hb; bio -> ilm; plag -> seri: ilm -> sph.

2907885-A

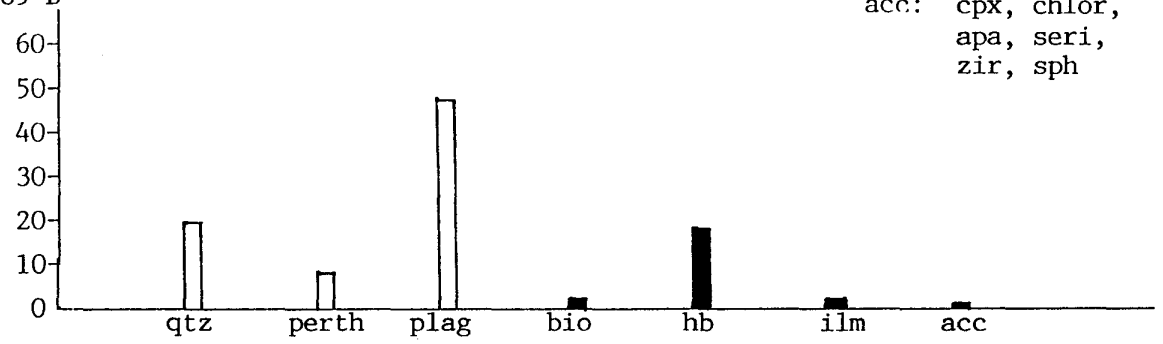


acc: seri, ilm, bio, musc, epi, sph

Granoblastic; very coarse. Quartz in long lens, up to 2 cm. Some myrmekite. Solid inclusions abundant in plagioclase. Perthite poikilitically encloses ovoid quartz crystals. Sphene-ilmenite intergrowth. Thin section cut very thin - difficult to estimate content.
•sph -> ilm; plag -> seri.

Thin Section No.

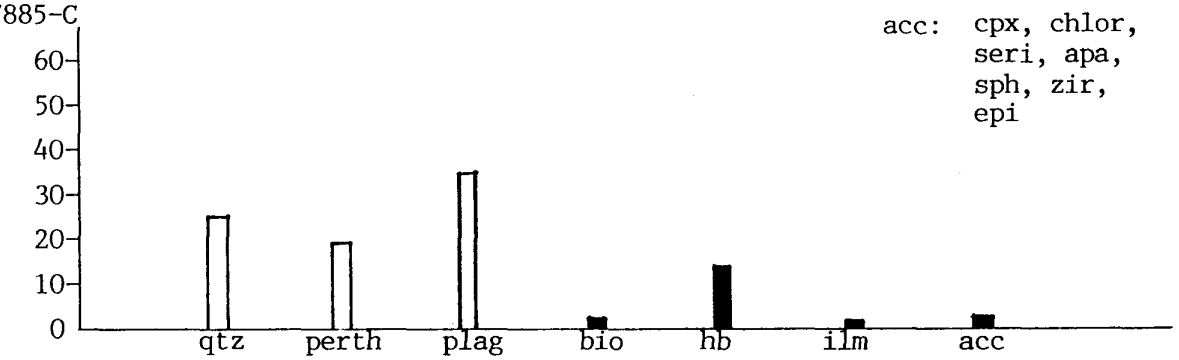
2907885-B



acc: cpx, chlor, apa, seri, zir, sph

Well foliated. Much chlorite-ilmenite intergrowth.
•cpx -> ilm; hb -> bio, hb -> ilm; bio -> ilm; plag -> seri.

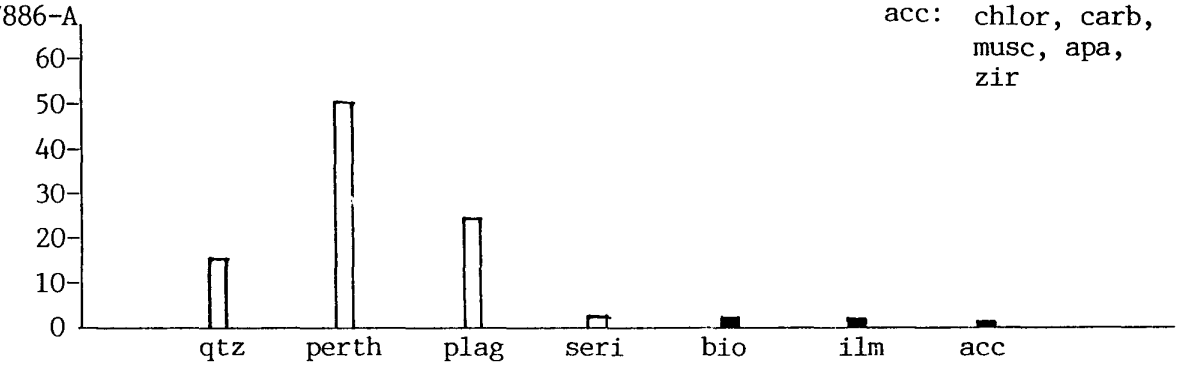
2907885-C



acc: cpx, chlor, seri, apa, sph, zir, epi

Foliated. Much myrmekite. Chlorite-ilmenite-hornblende intergrowth.
•cpx -> hb; hb -> bio, hb -> ilm, hb -> chlor?; bio -> ilm; plag -> seri.

2907886-A

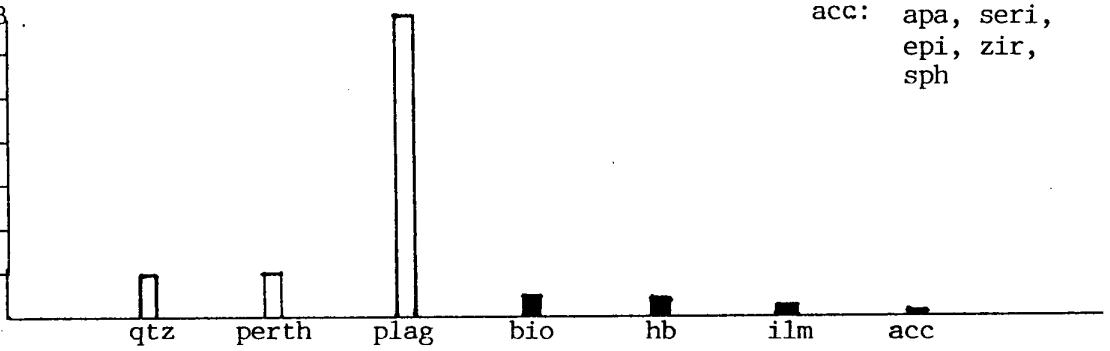


acc: chlor, carb, musc, apa, zir

Slight foliation of mafic minerals; leucocratic portion very coarsely granoblastic. Very large perthite and plagioclase crystals, over 1 cm. Quartz in long lens. Some myrmekite. Plagioclase "rutilated"; solid and fluid inclusions in quartz. Hornblende-biotite-chlorite intergrowth.
•hb -> bio; bio -> chlor; plag -> seri.

Thin Section No.

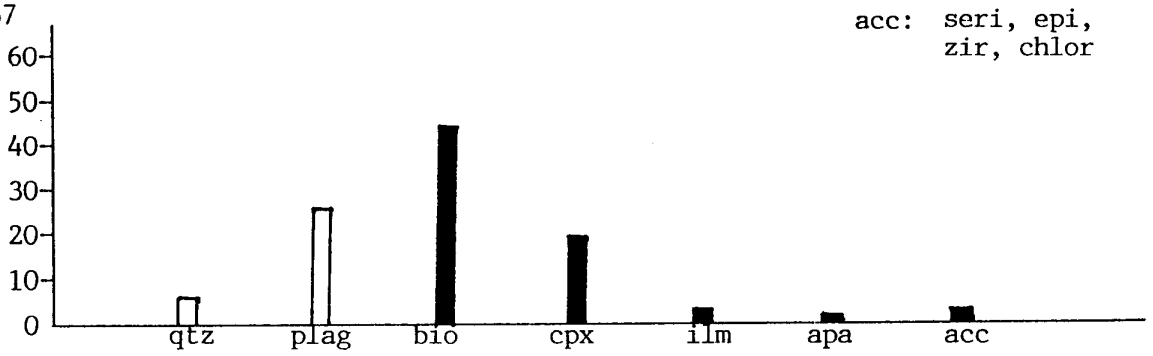
2907886-B



acc: apa, seri, epi, zir, sph

Predominantly granoblastic. Sphene surrounds ilmenite. Ilmenite-epidote intergrowth; ilmenite very particulate where intergrown with epidote. Solid inclusions in plagioclase; linear fluid inclusions in quartz.
•hb -> bio, hb -> ilm; bio -> ilm; plag -> seri.

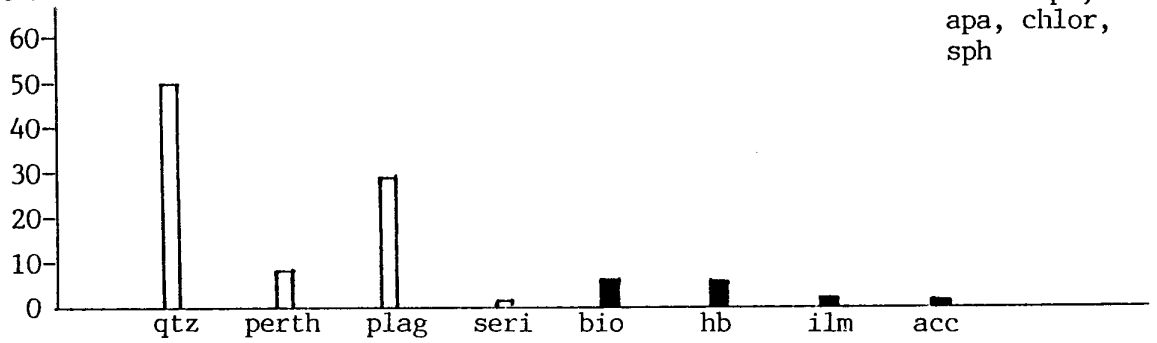
2907887



acc: seri, epi, zir, chlor

Well foliated. Epidote-ilmenite-biotite intergrowth; epidote-biotite-cpx intergrowth. Linear fluid inclusions in quartz.
•cpx -> bio; bio -> ilm; plag -> seri.

2907888-A



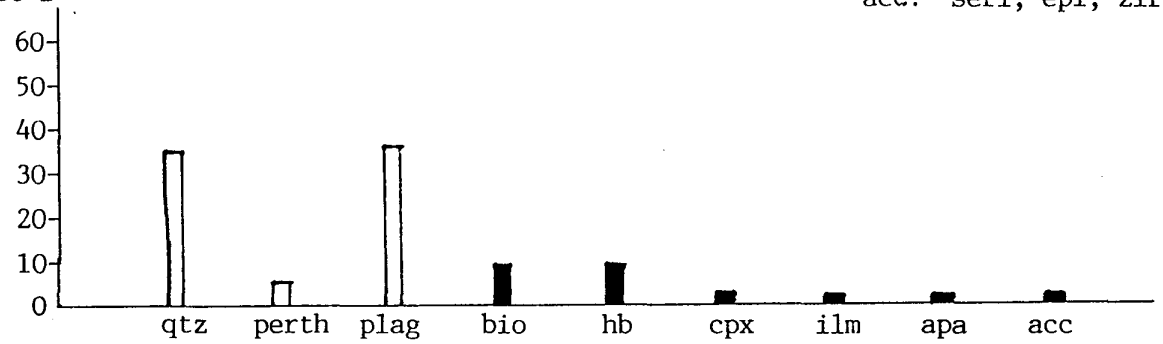
acc: epi, zir apa, chlor, sph

Predominantly granoblastic. Sphene fills ilmenite fractures.
•hb -> ilm; bio -> ilm, bio -> chlor; plag -> seri.

Thin Section No.

2907888-B

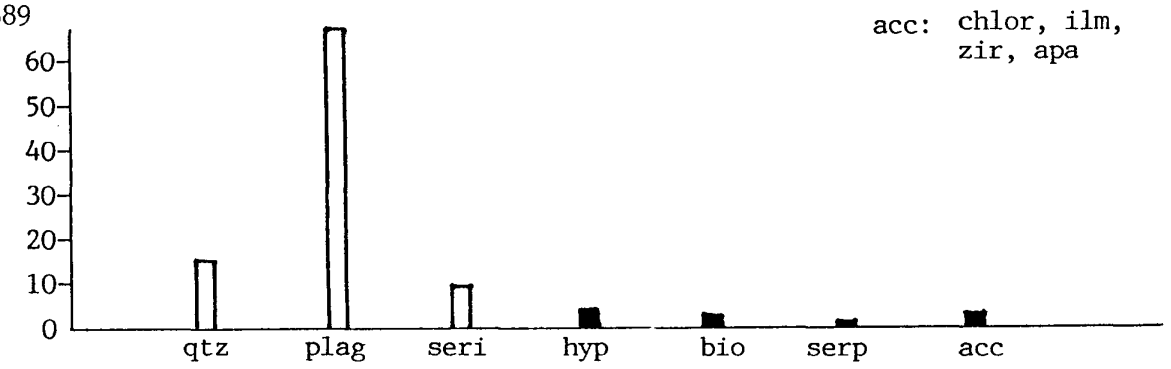
acc: seri, epi, zir



Foliated. Epidote-ilmenite intergrowth; ilmenite forms solid, ovoid rings with very particulate ilmenite and epidote intergrown within.
•cpx -> hb; hb -> bio, hb -> ilm; cpx -> bio; plag -> seri.

2907889

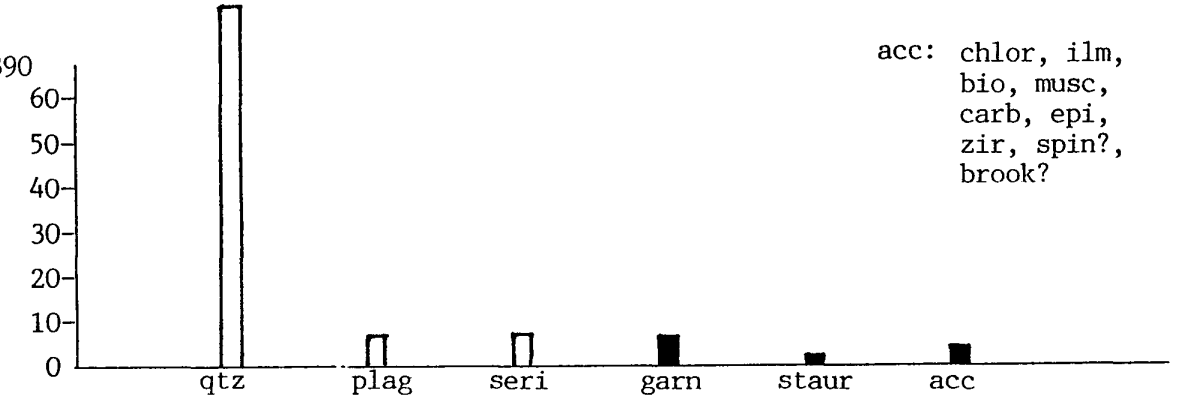
acc: chlor, ilm, zir, apa



Predominantly granoblastic, but mafic minerals, especially hypersthene, show lineation. Highly altered - shows much reaction. Texture finely crystalline-mosaic. Hypersthene highly fractured. Biotite very red. Chlorite fills large plagioclase fractures. Fluid inclusions in quartz.
•hyp -> serp?, hyp -> ilm, hyp -> chlor?, hyp -> bio; bio -> ilm; plag -- seri.

2907890

acc: chlor, ilm, bio, musc, carb, epi, zir, spin?, brook?



Very coarsely granoblastic. Complex mineralogy.Quartz in long lens, over 1 cm. Biotite very red. Ilmenite intergrown with unknown yellow, low relief mineral.Chlorite with particulate ilmenite within. Muscovite-carbonate-chlorite intergrowth. Staurolite highly altered; myrmekitic quartz within staurolite. Quartz with linear solid, fluid inclusions.
•staur -> garn?; bio -> chlor; plag -> seri.

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Thin sections with hypersthene are underlined in blue; locations where hypersthene found circled in blue.

Samples taken 7-24-87 ○ orange	Samples taken 7-29-87 ○ green	
1 2907871 A, B	1 2907871 A, B, C, D	11 2907881
2 2907872	2 2907872 A, B	12 2907882 A, B I, B II
3 2907873	3 2907873 A, B, C	13 2907883 A, B
4 2907874	4 2907874 A, B	14 2907884 A, B, C
5 2907875 A, B	5 2907875 A, B, C	15 2907885 A, B, C
6 2907876	6 2907876 A, B	16 2907886 A, B
7 2907877	7 2907877 A, B	17 2907887
8 2907878 A, B, C	8 2907878 A, B, C	18 2907888 A, B
9 2907879 A, B	9 2907879 A, B	19 2907889
10 2907880 A, B	10 2907880 A, B, C	20 2907890
11 2907881		

Location of Area Map Below

Note: 7-24 samples 7, 10, 11, and 7-29 samples 5-11 not on map.